DECOMMISSIONING OF

SOUTH BAY MINE

USING

ECOLOGICAL ENGINEERING

By M. Kalin

April 1993

EXECUTIVE SUMMARY

Decommissioning acid generating mining waste generally requires perpetual lime treatment. South Bay Mine, a copper/zinc operation active between 1971 and 1981, generated 0.75 million tonnes of tailings with a pyrite content of 41 % and a pyrrhotite content of 4 %. It is located 85 km northeast of Ear Falls in northwestern Ontario. Acid generation, based on the sulphur content, is expected to continue for a minimum of 1,110 years and a maximum of 35,742 years.

Oxidation rates in the tailings range from 76,000 mol Fe a^{-1} to 32,452,000 mol Fe a^{-1}. Perpetual lime treatment, although environmentally and economically unattractive, has remained the conventional approach. The option of using Ecological Engineering for the decommissioning of the site was assessed through a feasibility study in 1986.

Ecological Engineering uses ecological principles to reconstruct ecosystems within the waste management area. These ecosystems, through their natural water cleansing capacity, transfer the annual contaminant loadings from water to sediments.

Hydrogeological studies identified the main ground water flow paths from the tailings to Confederation Lake, and from the mine/mill site to Boomerang Lake. Ground water plumes and seepage paths were intercepted with diversion ditches, constructed on both the mine site and from the tailings, and directed to Boomerang Lake. Boomerang Lake was relegated to become the main polishing pond or treatment area for water from the mine site and the southern and western ground water plumes from the tailings. Decant Pond, on the tailings, also became a biological polishing pond.

Natural contaminant removal processes used in Ecological Engineering includes biological polishing for zinc and iron. Attached periphyton on brush and other substrates adsorb, co-precipitate, and sequester metals. ARUM (Acid Reduction Using Microbiology) is used for removal of sulphate and acidity. Microbial communities in chemically reducing sediments facilitate this process.

ARUM was initiated in Decant Pond in 1992, as both a physical and reducing (redox) barrier on the western beach, the entry point for acidic run-off and contaminated ground water. This process has been quantified for scale-up, through continued joint R&D, supported by CANMET, MEND and other mining companies.

Biological polishing was scaled up gradually, by annually increasing the surface area for periphyton growth. In Boomerang Lake this was done through additions of brush cuttings, whereas in Decant Pond, inert demolishing material was used to provide surface area for algal growth. In Mill Pond, the basin which contributes the largest contaminant loadings to Boomerang Lake, organic material was introduced, thereby assisting metal adsorption, ARUM and Biological polishing and overall reducing loadings to Boomerang Lake.

From the Biological polishing studies, the contaminant removal rates and estimates of the required surface area for periphyton growth were determined. If a substrate mass with a surface area three times that of the lake bottom was added, biological polishing alone could remove 40 % of the annual loading of zinc, and 100 % of the iron. In Mill Pond, 100 % + of the annual loadings of zinc and iron could be retained, thereby reducing the overall contaminant load to Boomerang Lake. Ecological Engineering measures were implemented gradually and all measures taken at the site have resulted in a average zinc concentration of 7.6 mg L^{-1} in 1992. Using monitoring data for Boomerang Lake, extrapolations indicate that, had no Ecological Engineering measures been implemented, zinc concentrations in the lake would likely have risen well above current levels.

Performance characteristics of the Biological polishing system are derived from the growth data, obtained in the field and the laboratory. The ranges in expected performance are large, mainly due to the limitations of methodologies for determining growth rates. In field experiments, growth can only be calculated using linear interpolation between two biomass measurements, which does not represent natural growth patterns. Furthermore, biomass which had accumulated on branches up until the time of sampling does not include that biomass which had sloughed off over the period since the last sampling time. While laboratory experiments examining periphyton growth demonstrated logarithmic growth, it was also apparent from these experiments that the waste water chemistry changes in the experimental vessel. Therefore, there are limitations during projection of laboratory-derived growth rates to arrive at estimates of Biological polishing performance in the field.

Decant Pond water quality is variable due to seasonal changes in run-off flow volumes. During periods of exceptionally high precipitation in spring and fall, elevated zinc concentrations are present. The monitoring data suggest that periphyton growing in Decant Pond effectively remove the zinc loading during the summer growing season.

Long-term trends in water quality measured in Boomerang Lake suggest that acidity and sulphate have steadily increased. Sedimentation studies indicate that iron, precipitated as solids and settled to the sediment surface, is periodically re-suspended in the lake.

In 1992, work addressing the residual contaminant loading in Boomerang Lake, Mill Pond, and Decant Pond was initiated. Processes, including ARUM and Biological polishing, are capable of removing the annual loadings, but cannot remove the entire contaminant loading which has accumulated during the estimated residence time of 3 years in Boomerang Lake.

Phosphate rock consumes acidity and precipitates metals. Any remaining (excess) dissolved phosphate, a major plant nutrient, is consumed by the periphyton population. Experimental trials using different grades of this material were first performed in the

laboratory, followed by field trials. When phosphate sand (750 kg) was applied to Mill Pond, significant amounts iron and aluminum were precipitated.

Phosphate powder (9 tonnes) was applied to areas around the northwest end of Boomerang Lake. While iron and aluminum concentrations in the surface waters were unaffected, concentrations of these elements decreased in bottom water overlying the sediments. The concentrations of metal precipitates increased in these sediments. Based on the increases in metals in the sediments following phosphate rock application, it was estimated that 6 % of the zinc, 74 % of the iron, and 10 % of the aluminum in the lake water were relegated to the sediment.

In 1992, five tonnes of coarse phosphate rock was applied to an area of the tailings where AMD was ponding due to the high water levels. In water leaving the area treated with phosphate rock, iron concentrations decreased from 53.5 to 12.9 mg L^{-1} and aluminum decreased from 34.3 to 5.2 mg L^{-1}, immediately following phosphate rock application.

Full implementation of Ecological Engineering measures has not yet been completed at the site. However, the extensive site-specific data set, and the progress made in technology development, facilitated an overall mass balance of annual contaminant loadings to Boomerang Lake and contaminant removal processes (Biological polishing and ARUM).

The annual loadings of zinc, iron, sulphur, and hydrogen ions to Boomerang Lake are 3.9, 2.7, 16, and 0.1 tonnes, respectively. The estimated annual zinc and iron removal capacity, when full implementation of the Biological polishing ecosystem in Boomerang Lake is complete, is 5 tonnes and 2.7 tonnes, respectively. The estimated annual removal capacity of ARUM (in Boomerang Lake sediments), based on sulphate reduction rates and alkalinity generation measured in other field systems, is 15.7 t of sulphur and 0.09 t of hydrogen ions.

Ecological Engineering measures for the South Bay site have targeted contaminant generation by the tailings deposit, surface water loadings to Decant Pond, and surface water loadings by the mill site. The potential of the underground workings to produce seepages draining to Confederation Lake during years with high run-off was not addressed until 1992. A large diversion ditch was completed in January 1993. Its performance and the effects on Boomerang Lake will be monitored in 1993. Work addressing ARUM activity in Boomerang Lake sediments and on the tailings beach of Decant Pond will continue. The accumulated contaminant load in Boomerang Lake, Mill Pond and Decant Pond will be addressed using phosphate rock.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF MAPS

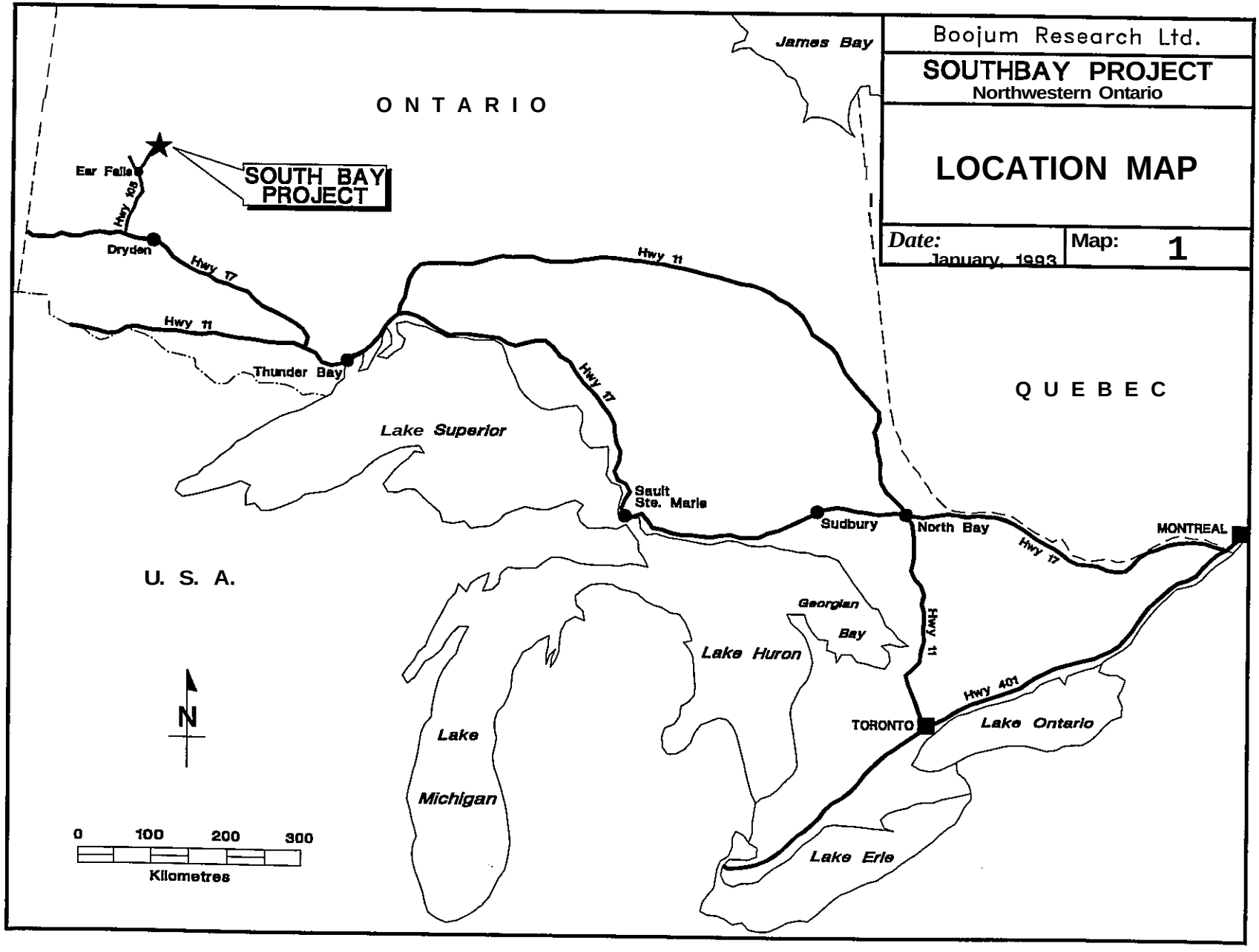
1. INTRODUCTION

The South Bay mine site is located 85 km northeast of Ear Falls in northwestern Ontario (Map 1). A copper / zinc concentrator operated at the site from 1971 to 1981. When the mine was shut down, a water management plan was developed by J.E. Hanna Associates Inc. in February 1986, for Selco Division of BP Resources. Perpetual lime treatment of Boomerang Lake, which displayed low pH values, and increasing zinc concentrations appeared as the only solution to decommissioning.

Perpetual lime treatment is environmentally and economically unattractive. Alternative options for the decommissioning of the site were sought by BP Resources. Boojum Research Limited was retained in 1986 to do a feasibility study on the application of Ecological Engineering. Ecological Engineering uses ecological principles to reconstruct ecosystems. In 1986, the methods required to apply the technology were in their infancy, but nevertheless, far enough along that the South Bay site was considered a suitable prospect for a demonstration of Ecological Engineering as a decommissioning technology.

The Ministry of Environment, Northwestern Region in Kenora, was informed of the proposed approach and approval, in principal, was obtained in September 1986 for the project. A monitoring schedule was developed by the Ministry on March 22nd, 1990.

After six years of R&D on the site, sixteen conference reports, journal articles, government reports and book chapters have been published on the project (Appendix A). This report summarizes the salient aspects of the Ecological Engineering measures implemented at South Bay.


Boojum Research Ltd.
SOUTHBAY PROJECT
Northwestern Ontario
LOCATION MAP
Date: January, 1993
Map: 1
James Bay
ONTARIO
SOUTH BAY PROJECT
Ear Falls
Hwy 105
Dryden
Hwy 17
Hwy 11
Thunder Bay
Hwy 11
Hwy 17
QUEBEC
Lake Superior
Sault Ste. Marie
Sudbury
North Bay
Hwy 17
MONTREAL
U. S. A.
Georgian Bay
Lake Huron
Hwy 11
Hwy 401
TORONTO
Lake Ontario
Lake Michigan
Lake Erie
N
0 100 200 300
Kilometres

Successful reconstruction of an ecosystem has to be based on a balance between contaminant release and contaminant removal rates. Contaminant release rates are dependent on the hydrological conditions in the tailings and on the mine site. Water is the transport medium of the acid-generated products. To determine the contaminant release rates, the hydrology of the site and the oxidation rate in the waste material have to be determined.

Hydrogeological studies identified the main ground water flow paths from the tailings and the mine/mill site to Boomerang and Confederation Lakes, respectively. Analyses of water collected from piezometers at different time intervals was used to determine the oxidation rate prevailing in the tailings.

Ground water plumes and seepage paths were intercepted from both the mine site and from the tailings, and directed to Boomerang Lake. Boomerang Lake was relegated to the role of a main polishing pond or treatment area. The constructed ground water interceptor ditches themselves served as polishing areas for treatment of contaminated water flowing towards Boomerang Lake. To curtail contaminant loading surges to Boomerang Lake during spring and fall, impoundments were built to pond water draining from tailings spill areas towards Boomerang Lake.

The first step in developing the Ecological Engineering system was the rerouting of surface water flows and interception of ground water plumes within the waste management area away from Confederation Lake, and directing contaminants carried in run-off towards Boomerang Lake. The second step was to quantify the contaminant release rates, so that annual contaminant loadings could be estimated. The third step consisted of the remediation work, which aimed to create conditions which would remove contaminants from the water by depositing them in the sediment. Reducing conditions have to prevail in these sediments to ensure that contaminants, including metals, are permanently detained.

Contaminant removal takes place through biological polishing, where attached periphyton adsorb, co-precipitate and collect contaminants. Biological polishing was quantified throughout the project for the Decant Pond located on the tailings, Mill Pond on the mine site and for Boomerang Lake. From the biological polishing studies, the contaminant removal rates, and the required surface area for periphyton growth were determined and formulated into a model to predict the expected performance of the contaminant removal process.

The most challenging component of Ecological Engineering is the development of methods which counteract acidity. A natural process which consumes acid generated by mine wastes is microbially-mediated acidity reduction and alkalinity generation in sediments. The appropriate conditions necessary for the microbial ecosystem to generate alkalinity in sediments were developed at other mine sites over the course of the project. The methodology is referred to as ARUM (Acid Reduction Using Microbiology). Through the addition of organic matter and nutrients to the sediments, alkalinity generation can be enhanced. In 1992, ARUM was implemented at the acid-generating tailings beach of Decant Pond, after carrying out several laboratory experiments to determine the suitability of various organic substrates.

The new ecosystems which are developing due to the Ecological Engineering measures are not anticipated to remove significantly more than the annual contaminant loadings carried in the run-off and seepage areas. A treatment method for the removal of the contaminant load which has accumulated over the previous three years, the retention time of Boomerang Lake, has to be found. Phosphate rock, a natural product mined by Texasgulf and used for the fertilization of acidic soils, appears suitable for this purpose. A one-time application of phosphate rock will neutralize the accumulated acidity and remove metals and provide more suitable conditions for algal growth. With provision of adequate substrate surface area, sufficient removal rates of contaminants by Biological polishing can be anticipated.

In 1992, tests with different grain sizes of natural phosphate rock were carried out in Boomerang Lake, Mill Pond, and on the tailings. The results of the scale up on ARUM and the phosphate rock are preliminary and reported under ongoing research activities in Section 6.

2. MONITORING

2.1 Introduction

An agreement was reached between the Ministry of Environment and BP Resources to surrender the mining leases to the Crown and define a restricted use for the waste management area of 75 ha. This area is defined in the letter of March 20th, 1992 from the Ministry to BP Canada Ltd. The objective is to retain contaminants within the waste management area.

2.2 Sampling Stations

The monitoring stations are given in Map 2. The data for C1 (Boomerang Lake oufflow in Lost Bay), C8 (boat landing bay of Confederation Lake close to the Mill site), and C11 (drainage from the tailings basin to Confederation Lake) are summarized in Tables 1 to 3, from the beginning of monitoring in 1986 to 1992.

The sampling location, C1, was moved to the mouth of Boomerang Lake in 1991. Previously, it was about two to three meters away from the lake oufflow in Lost Bay. The pH, zinc and sulphate, along with the acidity, were consistently higher than the regular sampling station, C1, and reflected the conditions in Boomerang Lake. In 1992 the official station was sampled again, and contaminant concentrations in water were found to be at or below normal levels (Table 1).

The year 1992 represented a period of very high precipitation, with a corresponding high surface run-off. The subsequent higher zinc loadings were noted as slightly higher zinc concentrations at sampling stations C8 and C11 (Tables 2 and 3).

If elevated contaminant concentrations were detected in Piezometer M56 (Map 2), this would indicate that a ground water plume is moving from the tailings towards Confederation Lake. This piezometer has been regularly monitored (Table **4).**

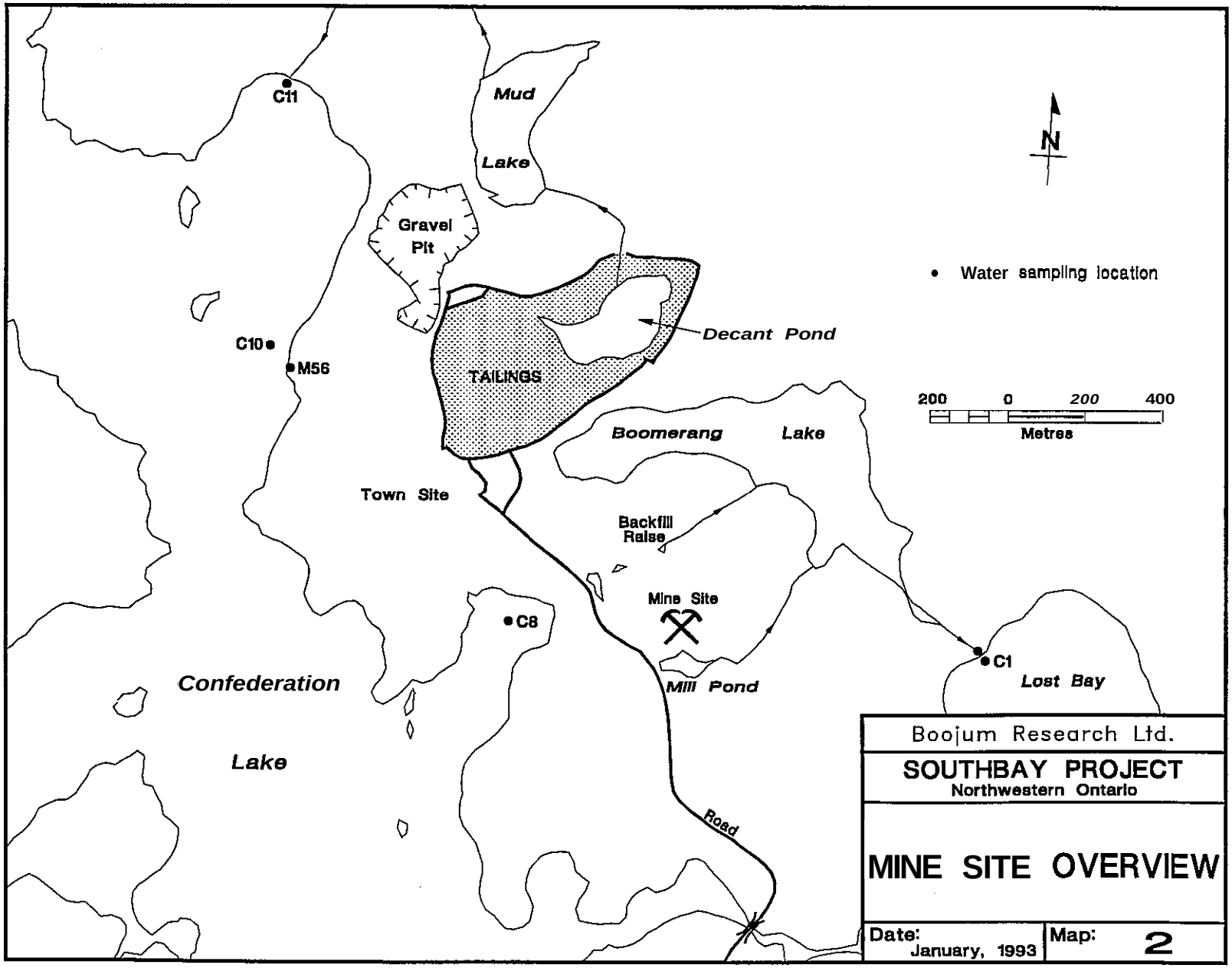

C11
Mud
Lake
Gravel
Pit
N
• Water sampling location
C10
M56
TAILINGS
Decant Pond
200 0 200 400
Metres
Boomerang Lake
Town Site
Backfill
Raise
Mine Site
C8
C1
Lost Bay
Confederation
Lake
Mill Pond
Road
Boojum Research Ltd.
SOUTHBAY PROJECT
Northwestern Ontario
MINE SITE OVERVIEW
Date:
January, 1993
Map:
2

TABLE 1: Chemistry of Sampling Location C1, Lost Bay

Sample Date		pH	Acidity mg/L as $CaCO_3$	SO4 mg/L	Zn mg/L
15-10-86		6.30	nd	11.7	1.70
5-04-87		6.05	nd	180.0	6.50
27-04-87		6.20	nd	13.8	0.16
31-05-87		6.64	nd	24.0	0.60
12-04-88		5.85	nd	66.0	<0.01
24-05-88		6.93	nd	23.4	0.40
23-06-88		7.46	nd	10.8	0.05
25-08-88		6.39	nd	3.3	0.01
14-05-89		4.59	nd	204.0	6.10
25-08-89		6.70	neg	63.0	1.80
25-08-89		6.70	43	174.0	0.09
3-06-90	*			4.5	<0.01
23-06-90		6.30	26	29.1	0.70
11-10-90		6.63	20	6.3	0.30
16-05-91	@	3.26	50	251.4	8.38
25-06-91	@	3.69	78	237.9	6.25
26-07-91	@	3.57	100	219.0	6.00
28-09-91	@	3.47	40	258.0	6.57
24-03-92	@	4.07	40	243.0	7.00
14-07-92		6.06	6.5	59.1	1.42
18-07-92		6.36	15	41.4	1.18
17-10-92		6.40	3.3	** 7.1	0.12

@ - change of sampling location

neg - negligible acidity

* - acidified on site, collected by Milt Ramsden

nd - not determined

** - determined by Boojum

TABLE 2: Chemistry of Sampling Location C8, Mill Site Bay

Sample Date	pH	Acidity mg/L as CaCO3	SO4 mg/L	Zn mg/L
15-10-86	6.90	nd	5.1	0.13
5-04-87	7.07	nd	5.1	0.40
27-04-87	6.60	nd	8.1	0.09
31-05-87	6.45	nd	6.0	0.01
12-04-88	6.55	nd	10.8	<0.01
24-05-88	7.22	nd	9.0	0.05
23-06-88	6.87	nd	7.8	0.04
25-08-88	6.16	nd	6.0	0.05
14-05-89	6.50	nd	9.3	0.20
25-08-89	6.80	nd	42.0	0.80
16-10-89	5.50	nd	10.2	0.01
3-06-90 *			3.6	<0.01
23-06-90	6.60	neg	6.3	0.01
16-04-91	7.39	6	3.0	0.07
15-05-91	5.98	10	8.6	0.22
26-07-91	6.04	17	6.0	0.30
25-09-91	7.28	neg	21.0	0.45
24-03-92	5.94	20	9.0	0.11
14-07-92	6.46	1.75	9.4	0.08
17-07-92	7.69	5	13.9	0.20
14-08-92	7.25	2	6.7	0.21
14-08-92	6.79	2.5	11.9	0.83
17-10-92	6.33	4.2	** 3.8	0.29

neg - negligible acidity

* - acidified on site, collected by Milt Ramsden

nd - not determined

** - determined by Boojum

TABLE 3: Chemistry of Sampling Location C11, Mud Lake Outflow

Sample Date		pH	Acidity mg/L as CaCO3	SO4 mg/L	Zn mg/L
15-10-86		6.60	nd	2.5	0.33
5-04-87		6.75	nd	6.8	0.03
27-04-87		6.60	nd	2.5	<0.01
31-05-87		6.55	nd	12.0	<0.01
24-05-88		7.15	nd	13.0	0.04
23-06-88		6.92	nd	8.1	<0.01
25-08-88		6.01	nd	12.0	0.01
14-05-89		6.26	nd	12.0	0.03
25-08-89		6.62	nd	11.0	0.30
3-06-90	*			1.3	<0.01
23-06-90		6.32	41	14.0	0.01
11-10-90		5.75	30	3.3	0.05
16-04-91	#	7.40	3	0.7	0.06
15-05-91	#	6.12	20	23.8	0.35
28-09-91		6.61	10	5.0	0.04
24-03-92		5.76	30	39.0	0.07
14-07-92		7.97	5.5	77.7	0.70
17-10-92		6.18	4.7	** 30.4	0.31

TABLE 4: Chemistry of Piezometer M56

Sample Date		pH	Acidity mg/L as CaCO3	SO4 mg/L	Zn mg/L
25-08-89		6.88	nd	7.3	0.10
14-10-89	&	6.50	nd	3.0	0.04
14-10-89		6.25	nd	2.7	0.10
23-06-90		6.51	nd	1.2	<0.01
11-10-90		6.02	nd	3.4	0.40
16-04-91		7.55	4	0.5	0.02
15-05-91	&	6.11	10	2.2	0.31
15-05-91		6.30	10	3.0	0.53
12-05-91		5.97	20	11.6	0.25
28-09-91		7.10	10	2.0	0.15
24-03-92		6.35	25	18.0	0.04
14-07-92		7.83	10	5.5	0.28
17-10-92		6.86	8.2	** 0.4	1.16

- sampled at C10

& - Confederation Lake shore, surface near M56

nd - not determined

* - acidified on site, collected by Milt Ramsden

** - determined by Boojum

In October 1992, piezometer M56 showed 1.1 mg L^{-1} zinc, the highest value reported for this station over the monitoring period. Zinc concentrations otherwise ranged from 0.01 mg L^{-1} to 0.5 mg L^{-1}. Because of the unusually high water levels, shore samples were also collected in 1992. The low zinc concentrations (0.103 mg L^{-1} of zinc) suggesting little impact to date.

The monitoring data collected by MOE for the project are summarized in Table 5. It can be noted that MOE data for zinc, sulphate and acidity are generally lower than corresponding data reported by Boojum. MOE pH data are generally slightly higher than corresponding Boojum data. This is likely due to differences in laboratories and the time span which elapses between chemical analysis and sampling. As all the Boojum samples are filtered through 0.45 μm filters and acidified within 24 h, it is not surprising that the Boojum contaminant concentration data are higher, as less time is allowed for chemical precipitation. Boojum's QA/QC procedures are given in the Appendix D.

In 1992, exceptionally high precipitation caused above normal run-off. The resulting high water table produced seepages which surfaced on the mine/mill site in 1992. Therefore, above normal levels of zinc were noted in Confederation Lake at station C8 near the beach of the mine/mill site (Map 2; Tables 2 and 5).

Phytoplankton diversity in surface water samples has been monitored once to several times per year at the C8 station. Although the zinc concentrations have increased noticeably at station C8, the species diversity of phytoplankton, monitored voluntarily at that station, has not changed since 1986 (Figure 1).

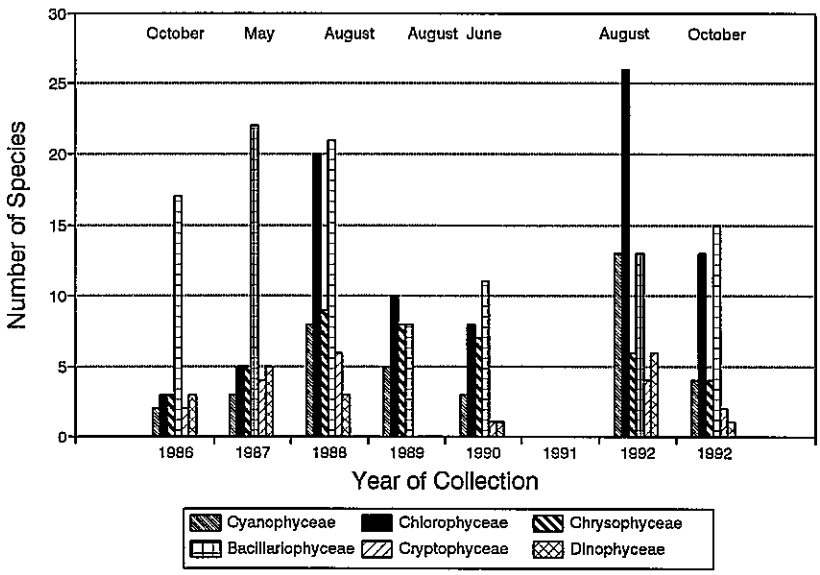
To gain a more complete understanding of the mine site conditions, a geophysical survey and extensive water sampling campaign were initiated during 1992. These investigations lead to the decision to construct a deeper diversion ditch extending further into the mine site, in order to drain a larger volume of water from the mine site

to Boomerang Lake. A smaller diversion of the Backfill Raise drainage basin was part of the original measures in 1987. The larger diversion ditch was completed by December 1992. Details of the work are reported in Section 7.

Table 5: MOE Data on Confederation Lake

Location	SCode	Date	Zn mg/L	pH	SO4 mg/L	Acidity mg/L
Confed. Lake @ Old Mine	OM	16-Oct-89	0.17	7.5	7.8	2
Confed. Lake South End	SS	12-Oct-90	0.03	7.3	6.1	2
Confederation Lake	C11	10-Apr-83	0.01	7.0	33.0	8
Confederation Lake	C11	12-Jun-84	0.01	7.0	65.0	9
Confederation Lake	C11	28-Aug-85	1.20	6.9	26.0	
Confederation Lake	C11	22-Oct-85	2.20	7.1	46.7	5
Confederation Lake	C13	16-Oct-89	0.04	7.6	6.3	1
Confederation Lake	C13	12-Oct-90	0.12	7.3	6.2	2
Confederation Lake	C13	16-May-91	0.01	7.3	6.6	2
Confederation Lake	C13	26-Aug-92	7.20	7.1	6.1	2
Confederation Lake	C8	25-Oct-82	0.09	7.9	7.0	3
Confederation Lake	C8	10-Apr-83	0.02	7.2	6.9	5
Confederation Lake	C8	12-Jun-84	0.15	7.3	7.3	2
Confederation Lake	C8	17-Sep-84	0.08	7.3	7.7	1
Confederation Lake	C8	28-Aug-85	0.09	7.5	6.2	
Confederation Lake	C8	22-Oct-85	0.06	7.5	6.2	1
Confederation Lake	C8	22-Jul-86	0.06	7.5	6.1	3
Confederation Lake	C8	24-May-88	0.05	7.3	8.9	3
Confederation Lake	C8	16-Oct-89	0.05	7.6	6.3	2
Confederation Lake	C8	16-Oct-89	0.13	7.4	7.4	2
Confederation Lake	C8	12-Oct-90	0.05	7.3	6.2	2
Confederation Lake	C8	12-Oct-90	0.09	7.3	6.6	3
Confederation Lake	C8	16-May-91	0.13	7.1	8.3	4
Confederation Lake	C8	16-May-91	0.07	7.4	6.6	2
Confederation Lake	C8	26-Aug-92	0.23	7.2	8.2	1

Fig. 1: Confederation L. Phytoplankton
Station C8 - Species Diversity



3. BOOMERANG LAKE - THE CONTAMINANT SINK

3.1 Introduction/History

Boomerang Lake is 1.2 km long, and 400 m wide along its widest transect. This shallow lake has a maximum depth of about 5.2 meters near station B4 (Map 3), with a mean depth of 4.0 m. The lake has a volume of just over 1 million m^3 and a surface area of 24 ha. Because the lake is shallow, the water is well mixed throughout the ice-free season. The annual base flow from the drainage basin to Boomerang Lake is estimated at approximately 344,000 m^3 a^{-1}, which results in a retention time of approximately 3 years.

The pH in Boomerang Lake had been dropping gradually for over 10 years, from a pH of about 6.3 in 1979, to a pH of 4 in 1986. Attached periphyton, which contain high iron and high zinc concentrations, were found growing on branches suspended in the lake. It was proposed that, through increasing the surface area for periphyton growth, biological polishing could remove enough zinc to maintain the zinc concentration at current levels and, as the population's standing biomass increased with time, reduce the zinc concentrations in the lake.

Research over the last several years has been carried out to quantify periphyton growth and metal removal in Boomerang Lake. Along with the quantification of the biological polishing process itself, measures were taken to reduce the contaminant loading from all sources to Boomerang Lake, through implementation of the same process at the mill site and in the ground water diversion ditch. The phytoplankton community was monitored and found to have a very similar composition to that of acid lakes on the shield, where the acidification is due to acid rain (Kalin et al. 1989b).

The sediments in Boomerang Lake are the ultimate recipients of the algal biomass and co-precipitates formed in the zinc-contaminated lake. Since these sediments have high

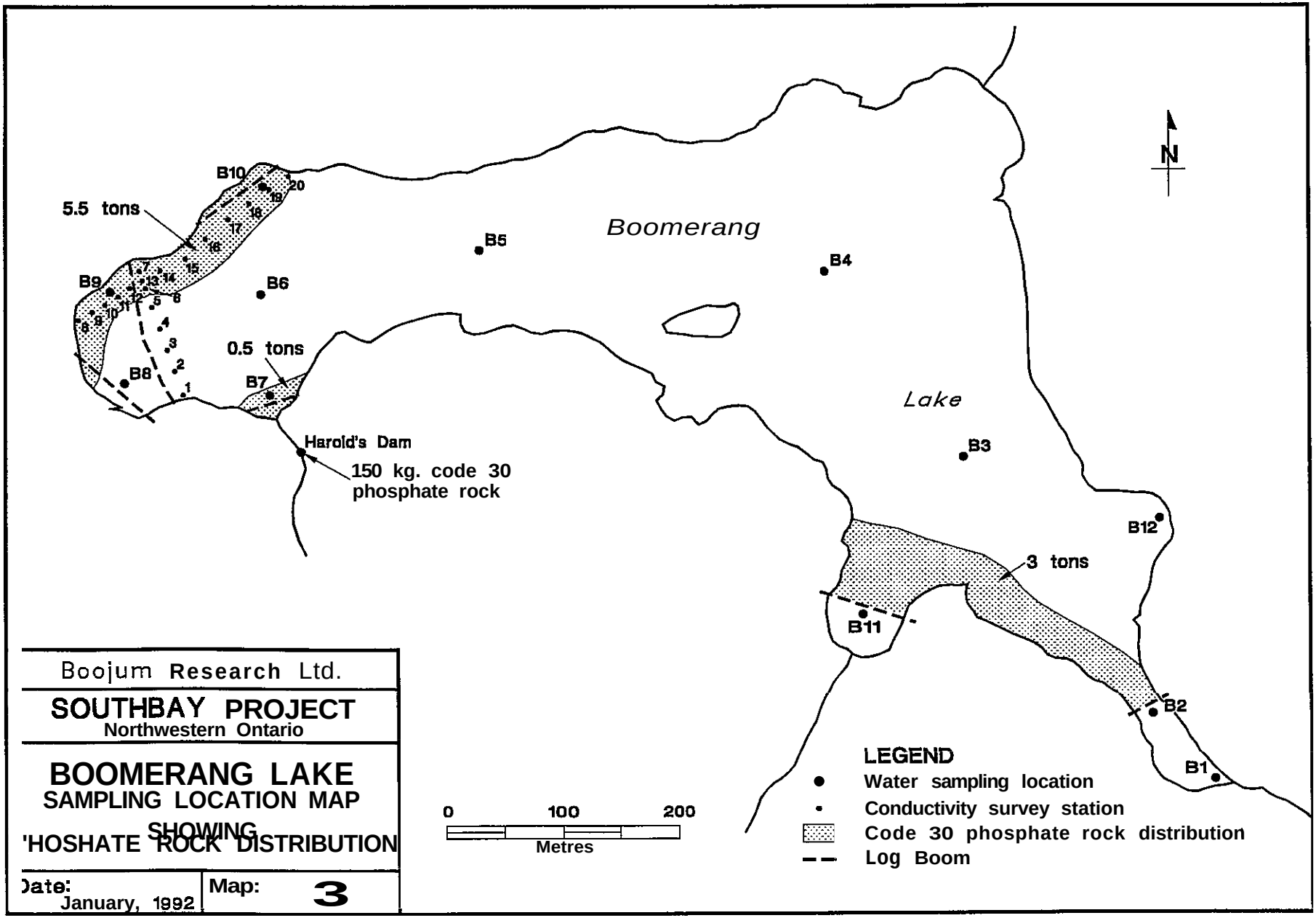
zinc concentrations, it is essential to keep them under reducing conditions. To provide such conditions, a sediment cover comprised of an acid-tolerant moss was envisaged.

Moss populating an acidic pond in the Backfill Raise area was transplanted to Boomerang Lake. While the moss grew well in the first two years, monitoring of moss growth was complicated following placement of brush in the same areas. This brush was added in order to provide surface area for periphyton. In retrospect, this was an error since, first, it was no longer possible to monitor the moss growth, as it was impossible to manoeuvre in the brush-covered areas with a boat; and second, the overlying brush and periphyton blocked light reaching the underlying moss. The current status of the moss population is unknown. Meanwhile, work on sediments in Boomerang Lake had been suspended until 1992.

3.2 Sampling Stations

Water quality monitoring has been ongoing in Boomerang Lake since 1971. Most of the water sampling has been done at station B9 which is at the boat landing (Map 3). Additional locations were sampled more frequently; B1 and B2 are at shallow (<0.5 m) locations at the outflow end of the lake. B11 is located in the bay into which Mill Pond run-off water enters. Station B7, B8, B9 and B10 are located at the shore where tailing spills entered the lake. B12 was set up as a "control" shore station, where clean or uncontaminated run-off enters the lake. The stations B3, B4, B5 and B6 are located in the centre of the lake.

Overall, water quality data for the lake shows only minor variation according to location. Uniform conductivity and pH profiles, and the lack of a thermocline over the water column, indicate that the lake is thoroughly vertically mixed during the ice free season. Boomerang Lake data from all sampling stations, including Boojum, BP and MOE data, were pooled to determine long term trends in water quality.


Boomerang
Lake
N
B10
B9
B8
B7
B6
B5
B4
B3
B2
B1
B11
B12
5.5 tons
0.5 tons
3 tons
Harold's Dam
150 kg. code 30
phosphate rock
0
100
200
Metres
LEGEND
Water sampling location
Conductivity survey station
Code 30 phosphate rock distribution
Log Boom
Boojum Research Ltd.
SOUTHBAY PROJECT
Northwestern Ontario
BOOMERANG LAKE
SAMPLING LOCATION MAP
SHOWING
'HOSHATE 'ROCK DISTRIBUTION
Date: January, 1992
Map: 3

3.3 Long Term Water Quality Trends

The pH of Boomerang Lake remained circumneutral between 1979 and 1985 but has since declined and, in 1992, the pH averaged 3.5 (Table 6). The data are grouped into three-year averages, as the retention time of Boomerang Lake is about three years.

Table 6: Water Quality in Boomerang Lake

Year	Iron (Fe)			Zinc (Zn)			pH			Acidity			Sulphate (SO4)		
	Aver. Conc. mg/L	N	Aver. Conc. mg/L	Aver. Conc. mg/L	N	Aver. Conc. mg/L	Aver.	N	Aver.	Aver. mg/L CaCO3	N	Aver. mg/L CaCO3	Aver. Conc. mg/L	N	Aver. Conc. mg/L
1979	0.55			3.55			6.31			2.0			90		
1980	1.36	105	0.89	4.76	104	3.98	6.26	104	6.36	-	4	4.0	-	6	109
1981	1.26			4.24			6.54			6.0			148		
1982	0.16			0.08			6.48			-			-		
1983	0.91	24	1.08	1.45	24	1.93	6.76	24	6.73	7.0	3	8.0	166	3	167
1984	1.78			3.48			6.83			8.5			168		
1985	0.93			3.5			7			-			-		
1986	1.17	63	2.64	8.4	63	7.21	4.34	49	4.50	-	0	-	169	55	194
1987	4.64			6.72			4.64			-			222		
1988	0.76			7.49			3.98			-			218		
1989	1.81	33	0.99	4.35	33	6.72	4.38	32	4.12	43.0	2	96.5	188	30	209
1990	0.53			7.40			4.40			150.0			202		
1991	1.65			7.32			3.71			65.5			226		
1992	1.66	32	1.66	8.04	32	7.66	3.54	31	3.63	54.4	27	61.0	228	29	227

Despite constant input of iron, present in seepages entering Boomerang Lake, iron concentrations have remained at between 1 to 2 mg L^{-1} between 1979 and 1992 (Table 6). The relatively constant iron concentrations are likely due to the following. First, water samples were consistently collected at the surface, eliminating possible variation with increasing depth in the water column. Second, as the lake is shallow and well mixed, relatively complete oxidation of iron can be expected; since the pH has remained above 3.0, this oxidized (ferric) iron precipitates as hydroxides. Should the pH have declined below pH 3, oxidized (ferric) iron would have re-dissolved, and higher iron concentrations would have been observed.

Zinc concentrations increased from 1979 to 1986, but have since remained relatively constant (Table 6). However, the pH of Boomerang Lake dropped drastically between 1985 and 1986, from a pH of 7 to a pH of 4.3. The pH remained relatively steady for the next four years, and then dropped again below 4.0 in 1991. Sulphate and acidity have been rising over the last 13 years. For comparison, the MOE data are summarized in Table 7. These data generally show the same trends as the larger data set collected by Boojum and BP.

Table 7: MOE Data on Boomerang Lake

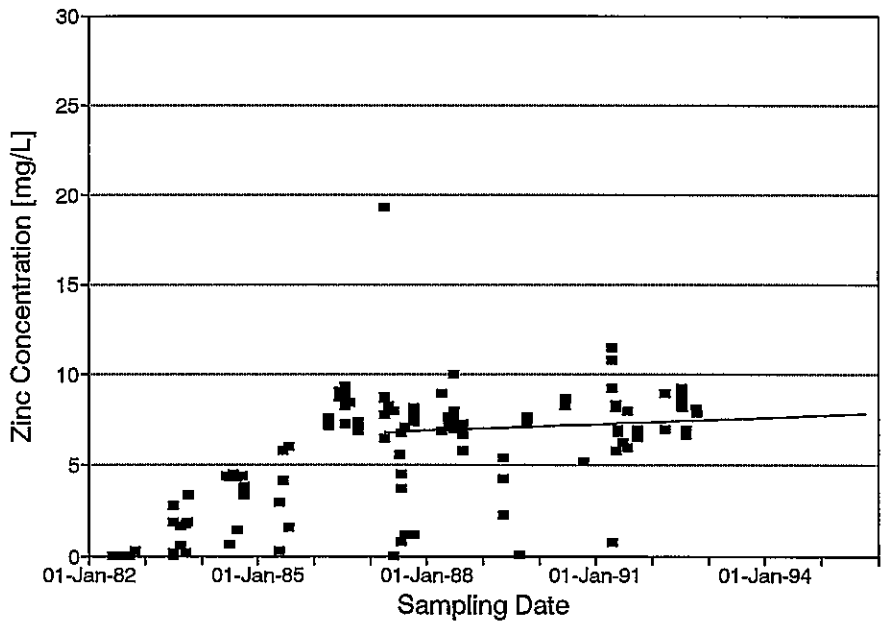
Location	SCode	Date	Zn mg/L	pH	SO4 mg/L	Acidity mg/L
Boomerang Lake	B9	25-Oct-82	3.2	7.5	153	6
Boomerang Lake	B9	10-Apr-83	3.4	6.8	166	7
Boomerang Lake	B9	12-Jun-84	4.4	6.2	171	9
Boomerang Lake	B9	17-Sep-84	4.4	5.4	164	8
Boomerang Lake	B9	28-Aug-85	7.0	5.4	171	
Boomerang Lake	B9	22-Oct-85	7.0	5.3	171	17
Boomerang Lake	B9	22-Jul-86	8.1	4.5	275	23
Boomerang Lake	B9	15-Jul-87	6.7	4.1	211	23
Boomerang Lake	B9	24-May-88	6.4	4.0	225	27
Boomerang Lake	B9	16-Oct-89	6.3	3.9	234	27
Boomerang Lake	B9	12-Oct-90	7.0	3.6	259	37
Boomerang Lake	B9	16-May-91	7.2	3.7	256	46
Boomerang Lake	B11	16-May-91	7.4	3.7	254	42
Boomerang Lake	B2	16-May-91	7.1	3.7	253	41
Boomerang Lake	B9	26-Aug-92	7.2	3.4	326	47

The Ecological Engineering project started with the feasibility study in 1986 and, in 1987, the first steps of remedial action were taken. Biological polishing for zinc and iron removal was the first process which was gradually scaled up. Brush cuttings were added to areas of Boomerang Lake in 1987, in areas where log booms could be installed to contain the brush. Additional brush cuttings were added in 1989.

Two other measures implemented in 1987 were, first, the grouting of the old acid-eroded ground tailings dike; second, the construction of ground water diversion ditches between the tailings and Confederation Lake, and the diversion of the Backfill Raise drainage basin towards Boomerang Lake. Both diversions increased the contaminant loadings to Boomerang Lake, although the ditches themselves served as biological polishing areas.

In Figure 2a, the zinc concentrations are plotted from 1982 to 1992. This represents a period equivalent to the time required for the Boomerang Lake volume to turn over three times. Although diversion of additional contaminant loadings via the new ditches to Boomerang Lake commenced in 1987, zinc concentrations remained relatively steady in the following years. Therefore, it can be assumed that the remedial measures were effective, to the degree that the additional zinc input did not manifest itself as higher zinc concentrations in Boomerang lake in the first three years following 1987.

Fig. 2a: Boomerang Lake
Zinc Concentration, 1982-1992



The slope of the increase in zinc concentrations between 1982 and 1987 suggests that the zinc concentration in Boomerang Lake was increasing by 2.2 mg L^{-1} a^{-1}. In all likelihood, this trend would have continued without remedial action. In fact, with the exception of seasonal changes, the concentrations of zinc have generally remained constant.

3.4 Contaminant Loading to Boomerang Lake

Expected contaminant concentrations in Boomerang Lake, had no remedial measures been taken, can be projected based on estimates of loadings to the lake from the tailings and the mill site. Following excavation of the diversion ditches, additional loadings have to be considered, including that from the Backfill Raise area and from the ground water diversion ditch between the tailings and Confederation Lake.

To determine the long term trends of the system, as well as the requirements of the biological polishing system, it is necessary to arrive at estimates of annual contaminant loadings, using the size of each drainage basin, the annual precipitation and contaminant concentrations measured in surface water, or in ground water destined to emerge as seepages.

The surface areas of drainage basins and associated concentrations of major elements contributing to Boomerang Lake, if Ecological Engineering measures had not been taken, are presented in Table 8a. The subsequent contaminant loadings to, and the projected contaminant concentrations in Boomerang Lake for this scenario are presented in Table 8b.

Table 8a: Areas and Contaminant Concentrations in Basins Draining to Boomerang Lake without Ecological Engineering

LOCATION	Drainage Basin ha	Zn mg/L	Fe mg/L	S mg/L	pH
Tailings	25.1	227	2065	2072.0	3.70
Mill Pond	24.3	278	15.5	480.0	3.34
Clean basin	85.0	0.29	0.03	2.2	6.33
TOTAL	134				

Table 8b: Contaminant Loadings to, and Projected Contaminant Concentrations in, Boomerang Lake without Ecological Engineering

LOCATION	FLOW RATES m3/annum	Zn kg/annum	Fe kg/annum	S kg/annum	H+ kg/annum
Tailings	1,200	272	2,478	2,486	89
Mill Pond	65,526	18,216	1,016	31,452	66
Clean basin	233,913	68	7	519	0.4
TOTAL	300,639	18,556	3,501	34,458	156
Lake Conc.		Zn (mg/L)	Fe (mg/L)	S (mg/L)	H (pH)
		54.1	10.2	100.5	3.3

Table 8c: Areas and Contaminant Concentrations in Basins Draining to Boomerang Lake with Ecological Engineering

LOCATION	Drainage Basin ha	Zn mg/L	Fe mg/L	S mg/L	pH
Tailings	25.1	227	2065	2072.0	3.70
Backfill Raise	12.7	6.9	2.9	49.3	3.87
Mill Pond	24.3	50	1	109.0	4.26
Pol. Ditch	3	6.5	0.095	516.0*	5.65
Clean basin	85.0	0.29	0.03	2.2	6.33
TOTAL	150				

* - determined by Boojum

Table 8d: Contaminant Loadings to, and Contaminant Concentrations in, Boomerang Lake with Ecological Engineering

LOCATION	FLOW RATES m3/annum	Zn kg/annum	Fe kg/annum	S kg/annum	H+ kg/annum
Tailings	1,200	272	2,478	2,486	89.1
Backfill Raise	34,788	240	101	1,715	8.3
Mill Pond	65,526	3,276	66	7,142	5.9
Pol. Ditch	8,176	53	0.8	4,219	0.05
Clean basin	233,913	68	7	519	0.4
TOTAL	343,603	3,910	2,652	16,082	103.7
Lake Conc.		Zn (mg/L)	Fe (mg/L)	S (mg/L)	H (pH)
		11.4	7.7	46.8	3.5

In Table 8c, the surface areas of drainage basins and associated concentrations of major elements contributing to Boomerang Lake, following Ecological Engineering measures, are presented. The subsequent contaminant loadings to, and the contaminant concentrations in Boomerang Lake are presented in Table 8d.

Estimates of loading from the tailings can be calculated, based on the metal concentrations in, and hydraulic conductivity in the vicinity of, piezometers located along the Boomerang Lake shore. A base flow of 1,200 m^3 a^{-1} is estimated, resulting in an average annual zinc loading of 0.27 t of zinc, 2.5 t of iron, and 2.5 t of sulphur, along with a loading of 89 kg of hydrogen ions from the tailings to Boomerang Lake (Table 8b and 8d). The loadings from the tailings are the same for both the scenario without Ecological Engineering (Table 8b) and the current status of the site following Ecological Engineering measures (Table 8d), since the grouting of the dam may only have a temporary effect and cannot be assumed to be long-lasting.

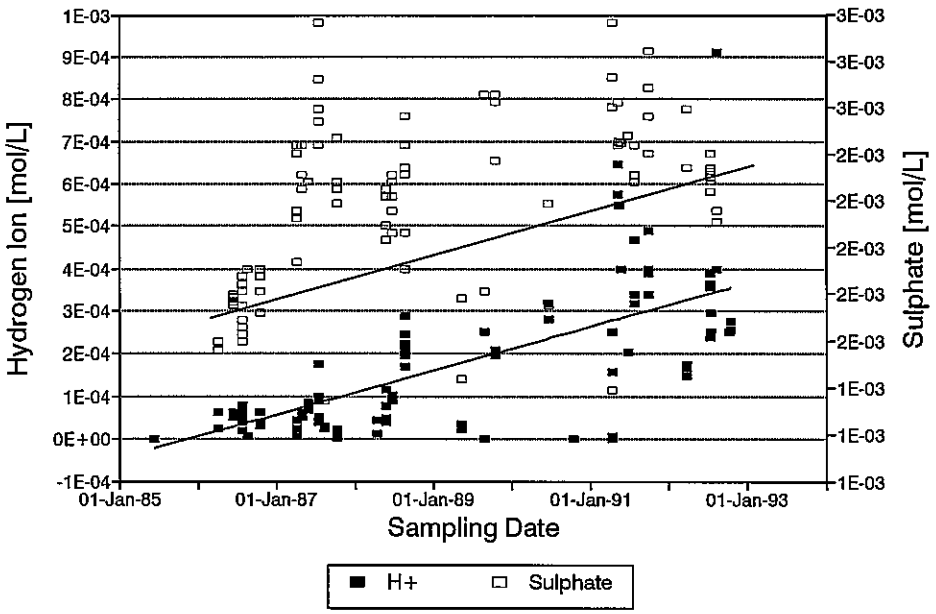
Had no changes in the drainage basins been engineered, the two major sources of contaminants would have been Mill Pond and the tailings alone. The loadings to Boomerang Lake in this scenario, using precipitation-based base flows, are 18.6 t of zinc, 3.5 t of iron, 34.5 t of sulphur, and 156 kg of hydrogen ions (Table 8b). Using the annual zinc loadings, zinc concentrations in Boomerang Lake should be 54 mg L^{-1}. However, this higher projection is expected, as the Mill Pond run-off area, prior to construction of the retaining pools, provided some polishing capacity which is not accounted for in this analysis.

To evaluate the capacity of the biological polishing system which has developed over the past three years, the annual loadings to Boomerang Lake need to be recalculated, taking into account the new drainage basins created by the diversions. In Table 8c and 8d, the reductions in loadings reflect the changes in the Mill Pond run-off. Contaminant concentrations in samples from the second of the three constructed retention ponds were used. Overall, the annual loadings are lower, with 3.9 t of zinc, 2.7 t of iron,

16 t of sulphur, and 104 kg of hydrogen ions. Using these estimated annual loadings, the zinc concentration for Boomerang Lake should be 11 mg L^{-1} (Table 8d). Again, this estimate is higher than that measured in Boomerang Lake in 1992 (7.6 mg L^{-1}).

An alternative approach to estimating contaminant loadings is available if Boomerang Lake monitoring data for sulphur and hydrogen is used. These two elements are less likely to be lost from solution via precipitation, compared to iron and zinc. In Figure 2b, the monitoring data for sulphur and hydrogen ion concentrations in Boomerang Lake are plotted for the period of 1985 to 1992 in molar concentrations. A linear regression line through the hydrogen ion concentrations suggests a slope of 1.40×10^{-7} mol L^{-1} d^{-1}. This rate, multiplied by 365 d a^{-1} and 10^9 L $lake^{-1}$, and converted to kg, is equivalent to a $[H^+]$ increase of 51.1 kg $lake^{-1}$ a^{-1}, half that of the 104 kg $lake^{-1}$ a^{-1} estimated in Table 8b using drainage basin base flow and concentration data. The linear regression for sulphate suggests an annual loading of 88,300 moles a^{-1}, which is equivalent to 2.8 t a^{-1}. Again, the estimate for sulphur, according to lake concentrations, is lower than the 16 t a^{-1} estimated in Table 8d, using base flows and concentrations in drainage basins.

Fig. 2b: Boomerang Lake
Long-term [H+] and [S]



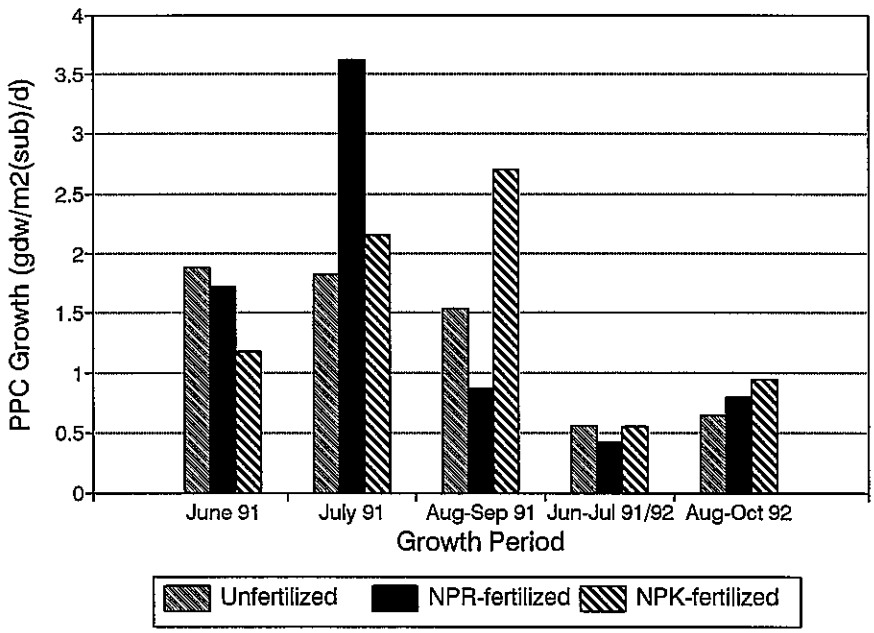
It can be concluded that the annual loadings to Boomerang Lake, estimated using two different approaches, range from 51 to 100 kg a^{-1} for hydrogen ions, and from 2.8 to 16 t a^{-1} for sulphur. These wide ranges reflect the complexity of the system, and the assumptions which have gone into the various estimates. However, the real values likely fall within these estimated ranges.

3.5 Biological Polishing Capacity

Once the range of annual contaminant loadings to Boomerang Lake has been derived, the current and required effectiveness of the biological polishing system has to be evaluated.

Periphyton growth rates, determined in the last two years, are presented in Figure 3. They are used to extrapolate the quantity of zinc which can be removed by the biological polishing process. Growth rates presented are based on the surface area of the substrate, in this case, spruce trees.

Fig. 3: Boomerang Lake Periphyton Growth Rates



The maximum growth rate estimates presented in Table 9a were used to construct Figure 3. The minimum growth rate estimates presented in Table 9a are calculated using time-weighted average growth rates calculated for all data. To estimate the biological polishing capacity, the maximum and minimum growth rates are multiplied either by a growth substrate area of 1, representing the surface area of the lake, or by a growth substrate area of 3, representing an area 3 times the surface area of the lake. This value of 3 times the surface area of the lake is derived from experimental pools, where the exact number of trees were counted and the surface area of the trees were estimated and could be associated with a pool volume. It was found that each m^3 of pond volume contained three meters of brush and bottom surface area. After multiplying the growth rate by the growth surface area available in the pond or lake, a value of primary productivity on a daily basis in kgdw $pond^{-1}$ d^{-1} is produced.

Zinc concentrations in periphyton from Boomerang Lake have been analyzed since 1986. The highest zinc concentration was 4,000 μg gdw^{-1}, while the minimum concentration (1992) was 473 μg gdw^{-1} (Table 9a). These values represent the amount of zinc which can be sequestered in each gram of periphyton. By multiplying this concentration by the primary productivity, or growth, of the population, a zinc removal from the lake to the biomass is calculated. This is expressed as grams of zinc removed per day in the lake. By multiplying this rate by the length of the growing season, conservatively estimated at 150 days per year, the total concentration of zinc removed by biological polishing can be estimated.

It was estimated that Boomerang Lake receives about 4 tonnes of zinc per year. In Table 9a, it can be seen that a periphyton population, growing at the maximum rate on a substrate area three times that of Boomerang Lake's surface area, would be able to remove 40% of the zinc loading. On the other hand, using minimum growth rates and a substrate surface area equivalent to Boomerang Lake's surface area, only 0.4 % of the zinc load would be removed.

Table 9a: Biological Polishing Extrapolations

	Growth Rate gdw/m^2/d	S.A. m^2/m^2	Growth Rate gdw/m^2/d	S.A. Water ha	Prim. Prod. kgdw/pond/d	Zn/PPC ug/gdw	Zinc Rem. g Zn rem./d	Zinc Rem. kg Zn/yr	Zn Load kg/yr	Removal %
Boomerang Lake										
max	3.6	1	3.6	23.9	860	4000	3440	516	3910	13
		3	10.8	23.9	2,580	4000	10319	1548	3910	40
min	0.9	1	0.9	23.9	215	473	102	15	3910	0.4
		3	2.7	23.9	645	473	305	46	3910	1
Mill Pond										
max	15.9	1	15.9	1.3	202	6188	1250	187	3523	5
		3	47.7	1.3	606	6188	3749	562	3523	16
min	4	1	4	1.3	51	4340	220	33	3523	1
		3	12	1.3	152	4340	661	99	3523	3
Decant Pond										
max	2.3	1	2.3	5.1	116	71200	8270	1240	17.8	6969
		3	6.9	5.1	348	71200	24810	3721	17.8	20907
min	0.5	1	0.5	5.1	25	4470	113	17	17.8	95
		3	1.5	5.1	76	4470	339	51	17.8	285

Table 9b: Periphyton Production, Laboratory Extrapolations

	Growth Rate gdw/m^2/d	S.A. m^2/m^2	Growth Rate gdw/m^2/d	S.A. Water ha	Prim. Prod. kgdw/pond/d	Zn/PPC ug/gdw	Zinc Rem. g Zn rem./d	Zinc Rem. kg Zn/yr	Zn Load kg/yr	Removal %
Mill Pond										
max	40.5	1	40.5	1.3	514	20000	10287	1543	3523	43.8
		3	121.5	1.3	1,543	20000	30861	4629	3523	131.4
min	27.2	1	27.2	1.3	345	4340	1499	225	3523	6.4
		3	81.6	1.3	1,036	4340	4498	675	3523	19.1

The approach taken in estimating the capacity of the system is conservative, and assumes that the annual contaminant loadings have to be dealt with in a 150 day growing season, which is not the case. Furthermore, other natural removal systems are in place, such as sedimentation/precipitation and co-precipitation, which further remove zinc from the water. These factors will be examined in the next section.

Since Mill Pond is the major source of contaminant loading to Boomerang Lake, biological polishing has also been implemented in Mill Pond. Biological polishing in Mill Pond would significantly reduce the loading to Boomerang Lake, which in turn will reduce zinc concentrations in water leaving Boomerang Lake.

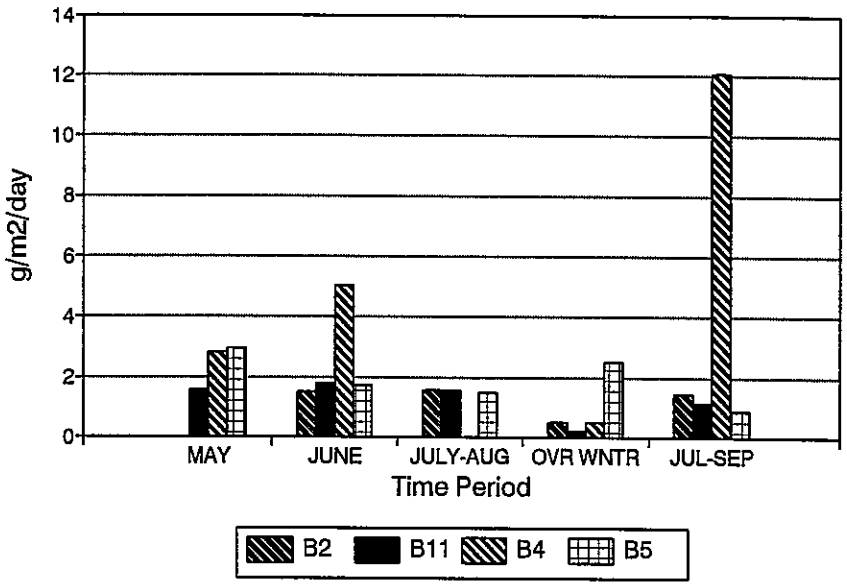
Growth rates under different light conditions have been tested in the laboratory. Details of results of these experiments are discussed in section 3.7.2. Zinc removal estimates can be calculated using the minimum and maximum logarithmic growth rates calculated from these data, in conjunction with zinc concentrations in periphyton growing in the first retention pond below Mill Pond (Table 9b). Estimates of zinc removal using these data are significantly higher than those based on periphyton growth rates based on growth rates estimated from field data collected in Mill Pond. Removal estimates ranged from 20 % to 324 % of the annual zinc loading (Table 9b).

3.6 Precipitation/Sedimentation in Boomerang Lake

Sedimentation traps measure the gross downward flux of particles in a water body. In May 1991, five sediment traps were placed in Boomerang Lake and Decant Pond. Traps were located near the outflow of Boomerang Lake in 2 m of water, at B11 in 2.5 m of water, at B4 in 6 m of water, at B6 in 5 m of water (Map 3). A trap was also located along the log boom in Decant Pond in 2 m of water.

Over the summer of 1991, the winter of 1991/1992, and the summer of 1992, these traps collected sediment at the rates shown in Figure 4. From these data, a time-averaged sedimentation rate of 0.77 g m^{-2} d^{-1} was calculated. The sedimentation rates were higher in summer periods than in winter periods.

Fig. 4: Boomerang Lake
Sedimentation Rates



The average daily sedimentation rate multiplied by 365 days, gives an annual sedimentation rate of 281 g m^{-2} a^{-1}. From ICP analysis, the suspended solids caught in the traps have an average iron concentration of 0.17 g gdw^{-1}. When this average is multiplied by the annual suspended solid loading, an iron loading of 50 g m^{-2} a^{-1} is calculated. When this is further multiplied by the area of the lake (238,861 m^2), 11.9 tonnes of iron are projected to sediment/precipitate in Boomerang Lake each year. This is four times the estimated iron loading in drainage entering Boomerang Lake.

Because the lake is shallow and long, it is quite possible that settled solids, especially those at the north end of the lake, could be re-suspended, and the sediment traps

capture these solids as well as new solids entering or forming in the lake due to run-off. In fact, the highest sedimentation rates were found in B4 and B6 sediment traps in the north and west end of the lake, the same areas receiving the brunt of the prevailing northwest winds. Such wind-driven re-suspension of sediments is common in shallow lakes, where as much as 16 g m^{-2} d^{-1} of solids (compared to 0.77 g m^{-2} d^{-1} in the current scenario) can be traced to re-suspension (Ten Hulscher et al. 1992).

The same calculation can be applied to zinc. In this case, the zinc content of the trapped solids (5887 μg gdw^{-1}) was multiplied by the estimated cumulative mass of trapped solids over **1** year, then by the lake area. From this calculation, an estimated 395 kg of Zn are settling to Boomerang lake sediments per year. If this quantity of zinc is added to the estimated 1.6 t of zinc captured by periphyton, then 50 % of the annual zinc loading is being removed by biological polishing and suspended solid settling.

This estimate of zinc removal by biological polishing is based on several parameters, where large variation in the estimated available surface area, and inherent variability in the methodology used to determine growth rates of the attached periphyton exist. Given that these two parameters are key factors in the evaluation of the overall capacity of the system, they are discussed in more detail in the next sections.

3.7 Periphvton-Precipitate Complexes

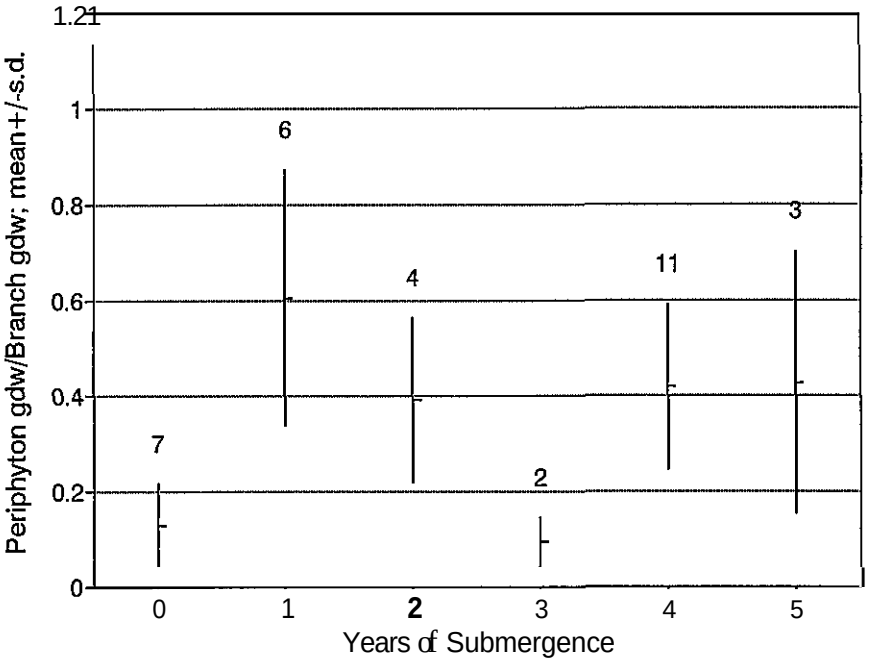
Periphyton have been shown to accumulate zinc and other metals through adsorption and precipitate sieving. Subsequently, in Boomerang Lake, precipitates are typically imbedded in the periphyton biomass attached to substrates. This mixture could be termed the periphyton-precipitate complex (PPC). In order to assign periphyton populations the role of removing large quantities of dissolved and precipitated contaminants, the growth of these populations and scale-up potential must be assessed.

Between 1987 and 1991, brush and trees from the area around the South Bay mine site, primarily black spruce, were added to provide surfaces for periphyton growth to areas of Boomerang Lake where the substrate could be contained by log booms.

Brush and spruce trees were placed in Boomerang Lake in 1987, 1988, and 1990. In 1987, 260 trees were distributed over four areas. The two areas which received the greatest amount of substrate were near the oufflow (B2), and the area where Mill Pond outflow enters the lake (B11; see Map 3). In 1988, more substrate was added to B2 area; each tree was tagged, in order that the newer trees could be differentiated from trees added in the previous year. In 1991, 30 truck loads of brush and trees were placed in the vicinity of station B8. With substrates placed in Boomerang Lake in three separate years, it was possible to set up a sampling program to test the effect of submergence time on the establishment and development of periphyton within the periphyton-precipitate complex (PPC).

Figure 5 shows the mass of PPC found on spruce branches submerged for different lengths of time. The mass of PPC per gram of spruce branch was at a maximum after 1 year of submergence. Since then, with the exception of 1989, the average mass of PPC per gram of spruce branch has remained fairly constant, at just above 0.4 gdw PPC per gram of spruce branch.

Fig. 5: Boomerang Lake Periphyton
Mass **vs.** Submergence **Time**



While the mass of PPC on branches has remained relatively constant over the last 5 years, the percentage of iron in the PPC has not. Iron concentrations in the PPC from Boomerang Lake have been increasing since measurements began in 1986 (Figure 6). At the same time, zinc concentrations in the PPC have been decreasing (Figure 7). Thus, while PPC mass has remained constant, the LOI has decreased each year, suggesting that the precipitate portion of the PPC is increasing.

Since the pH of Boomerang Lake is around 3.5, zinc removal from water cannot be through direct precipitation, but must be occurring by co-precipitation or adsorption. Two observations suggest that zinc uptake by the PPC is directly dependent upon adsorption by living periphyton biomass component, and not via co-precipitation of zinc upon formation of iron precipitates captured by the periphyton-precipitate complex. First, given that precipitate portion of the PPC is increasing, the periphyton portion must be decreasing; the gradual decrease in zinc removal by the PPC is, therefore, likely due to the diminishing fraction of periphyton in the PPC. Second, if the primary form of zinc removal was co-precipitation with iron, then zinc and iron concentrations in the PPC should be correlated, which is not the case.

Fig. 6: Boomerang Lake Periphyton
Iron Concentrations vs. Time

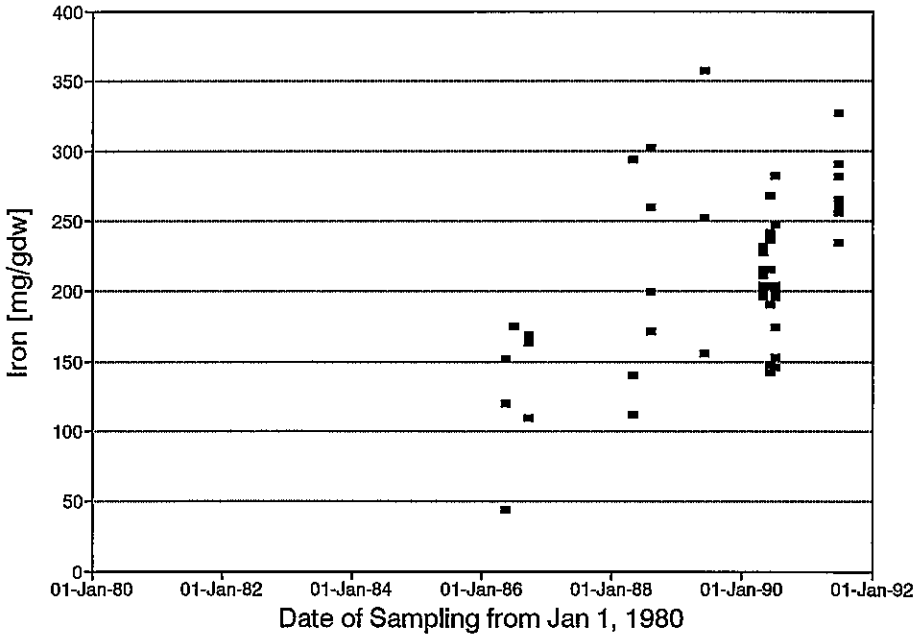
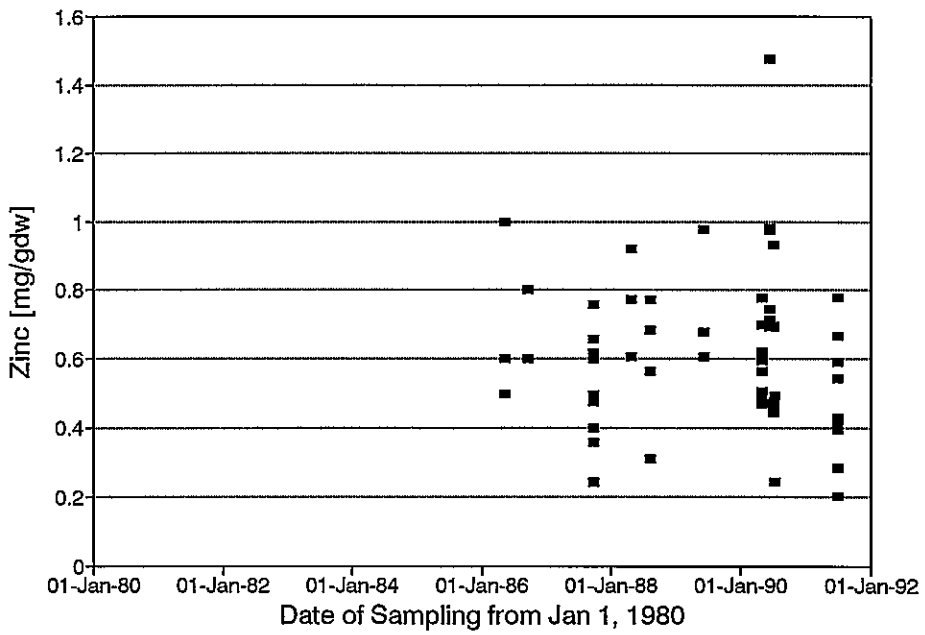


Fig. 7: Boomerang Lake Periphyton
Zinc Concentrations vs. Time



From quantification of the PPC biomass on substrates over several years, it is evident that the PPC biomass per unit of substrate has remained relatively constant. However, quantification of standing biomass, alone, provides no information concerning the production rate of new biomass, nor the rate at which biomass is lost from the substrate by sloughing. This information is required for estimating the long term performance of biological polishing using periphyton populations.

Large patches of PPC biomass accumulated on branches likely slough many times each year, due to wave action during storms and to abrasion by ice during spring break-up. Remaining periphyton is the older layers which were tightly bound to the substrate surface beneath the sloughed patch. The long term trend of increasing iron content and decreasing zinc content may reflect this sloughing process. In light of these observations, a field method for quantifying biomass growth and biomass loss by sloughing was developed.

Experimental devices, containing panels of substrate held in place with netting, were positioned horizontally below the water surface of Boomerang Lake. Plastic bags were positioned below the panels in order to trap any biomass sloughed from the substrate. The set-ups were periodically recovered. The biomass was quantified which collected on the substrate, on the netting and in the bag. Therefore, using these set-ups called Peritraps, substrate surface areas were provided so that growth and sloughing rates could be estimated.

3.7.1 Peritraps

Peritraps were placed in Boomerang Lake at B2 and B11 (Map 3). The PPC biomass was periodically sampled weeks to months following set-up. From these data, PPC growth rates were as high as 3.6 gdw m^{-2} (subst) d^{-1}, measured over July 1991. As expected, growth rates were lowest in winter; as little as 0.4 gdw m^{-2} (subst) d^{-1} grew

over the winter of 1991/1992 (Figure 3). The overall average PPC growth rate over the two year study period was 1.43 gdw m^{-2} (subst) d^{-1}.

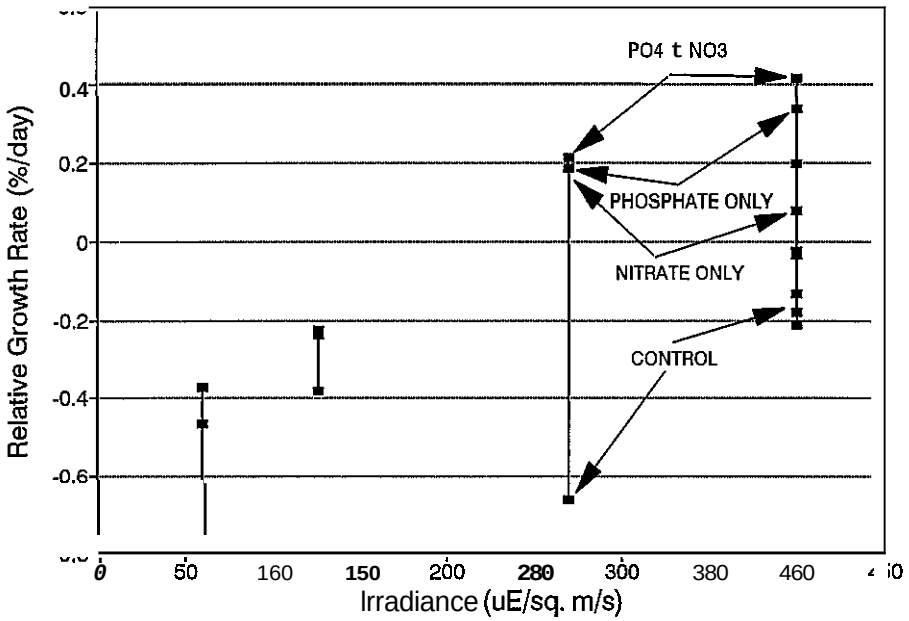
Because the peritraps were sampled weeks to months following set-up, variation in growth rates over the incubation period is unknown. Therefore, when estimating growth rates, the simplest relationship, linear, between biomass and time has to be assumed, according to the relationship, GR = (W2-W1)/Δt. However, in all likelihood, growth of PPC biomass in the peritraps over the weeks of incubation started with an initial colonization phase characterized by slow growth, followed by exponential growth, then moderate growth, depending on the extent to which substrate surface area was cleared by sloughing. In order to examine these phases in more detail, growth rates were measured in the laboratory, where exponential growth could be evaluated.

3.7.2 Laboratory Growth Experiments.

Growth rates of *Ulothrix*, a filamentous green alga collected from Decant Pond, were measured in laboratory cultures supplied with Boomerang Lake water. Cultures were incubated at 25°C under daylight fluorescent bulbs providing a 12:12 h light:dark cycle. In some treatments, Boomerang Lake water was amended with nitrate and phosphate. Relative growth rates, in % per day, were calculated from the algal biomass fresh weight gain/loss measurements made two weeks after set-up. The relative growth rates, presented in Figure 8, were highest in those treatments that both received additional nutrients (nitrate and phosphate) and the highest irradiance (400 μE m^{-2} s^{-1}, equivalent to 1/4 full sunlight). The highest growth rate, calculated as a logarithmic growth rate (RGR= 100*ln(W2 $W1^{-1}$) At"), was 0.4 % per day. This means that the periphyton added 0.4 % to the biomass each day. Because clumped periphyton biomass in the laboratory set-ups was grown under low light intensities and was supplied with a finite amount of nutrients, these growth rates are poor compared to field

growth rates. In the field, periphyton population structure, light and nutrient conditions are more favourable for growth.

Fig. 8: Decant Pond Ulothrix Growth Rates



In another series of experiments, one-tenth of the biomass used in the experiment above (approximately 0.1 gfw) was fragmented in a Waring Blender, and pipetted into 500 mL jars. After about 1 week, algal biomass was quantified by filtering material through a filter paper, drying and weighing.

Relative growth rates are shown in Table 10a, according to the culture solution used and amendments added. Although similar growth conditions were provided as before, with the lower initial biomass, much higher growth rates by periphyton were achieved.

Table 10a: Laboratory Growth Rate Summary

TAXON and ORIGIN	WATER	TREATMENT	End pH	GR (%/d)
Ulothrix1 Mill Pond	Mill Pond		3.8	5.7
Ulothrix1 Mill Pond	Mill Pond	+PO4 +NO3	4.6	7.3
Ulothrix1 Mill Pond	Growth Medium		7.3	8.5
Ulothrix2 Mill Pond	Mill Pond		3.8	3.9
Ulothrix2 Mill Pond	Decant Pond		6.0	5.1
Ulothrix2 Mill Pond	Boomerang Lake		3.5	5.1
Ulothrix Selminco	Boomerang Lake	+PO4	3.5	2.7

Ulothrix 1 and 2 different collection dates

Because of the relatively short incubation periods, several different strains of *Ulothrix* and South Bay waters could be tested. The highest growth rate recorded under these conditions was 8.5 % d^{-1} in artificial growth medium, and 7.3 % d^{-1} in Mill Pond water with added nutrients. The growth rate of South Bay *Ulothrix* in Boomerang Lake water was 5.1 % d^{-1}.

The growth rate of *Ulothrix* culture in Boomerang Lake water determined in the laboratory was used in conjunction with the mean biomass of periphyton on spruce branches found in Boomerang Lake (0.4 gdw $gdwB^{-1}$; Figure 5) to calculate a field/lab primary productivity estimate. According to this calculation, the primary productivity in Boomerang Lake is 0.02 gdw periphyton gdw $branches^{-1}$ d^{-1}. The average surface area of a Spruce branch sampled from Boomerang Lake is approximately 0.0089 m^2 gdw^{-1}. Therefore, on a square meter basis, the estimated growth rate of the algal portion of the PPC is 2.3 gdw m^{-2} d^{-1}.

In the field, not only does periphyton biomass accumulate on substrates, but also on precipitates, making up the remainder of the PPC mass. In 1992, PPCs contained approximately 80 % precipitate. Therefore, taking the above estimate of productivity and adding the precipitate fraction, the PPC growth rate is 11.5 gdw m^{-2} (subst) d^{-1}. This is three times the maximum growth rates, derived from field growth rates in peritraps, used in Table 9a to estimate the biological polishing capacity.

3.8 Total System Capacity Estimates

Estimates of biological polishing capacities were derived from experimental data from the field and laboratory. In Table 10b, a summary is provided of the annual loadings to Boomerang Lake and the maximum loadings which can be expected to be removed by biological polishing in both Mill Pond and Boomerang Lake. Using the maximum growth rates measured in Mill Pond, the biological polishing capacity is larger than estimated loadings. With diminishing contaminant concentrations, biological polishing will be unable to scavenge all contaminants; therefore, 90 % removal (3523 kg a^{-1}) was used as the annual removal rate by biological polishing in Mill Pond.

Table 10b: Biological Removal Systems - Boomerang Lake

Contaminant	Zn	Fe	S	H+
	kg/a	kg/a	kg/a	kg/a
LOADINGS	3,910	2,652	16,082	103.7
Biological Polishing				
Mill Pond	3,523	66	-	-
Boomerang Lake	1,548	2,652	-	-
ARUM				
Flow-through N. Ont.	-	-	10,963	89.6
Limnocorral Nfld.	-	-	13,830	97.5
Limnocorral N.S.			22,572	96.0
TOTAL REMOVAL	5,071	2,718	15,788	94.4

An Ecological Engineering system in Boomerang Lake must also remove both sulphur and hydrogen ions, in addition to zinc and iron. Removal of these contaminants is possible via a second biological process, ARUM. ARUM experiments were not only performed in 1992 using South Bay effluents (presented in Section 6); sulphate and hydrogen ion removal rates have been quantified at three other sites across Canada. The details of these projects will be available in publications in 1993.

In field experiments, sulphate removal rates from water overlying ARUM sediments ranged from 0.22 to 0.63 g S m^{-2} d^{-1}. Hydrogen ion decreases ranged from 2.5 to 2.7 mmol m^{-2} d^{-1}. Using these rates, assuming an active ARUM sediment in Boomerang Lake, the following removal rates were calculated based on a short, 150 day, growing season. As seen in Table 10b, removal of the annual sulphate and hydrogen ion should be near complete when ARUM sediments are in place. Sediment-based microbial activity is not limited to a summer growing season, as temperature fluctuations in the sediments are greatly attenuated, compared to the overlying water. Again, conservative estimates were used to estimate these capacities upon scale-up.

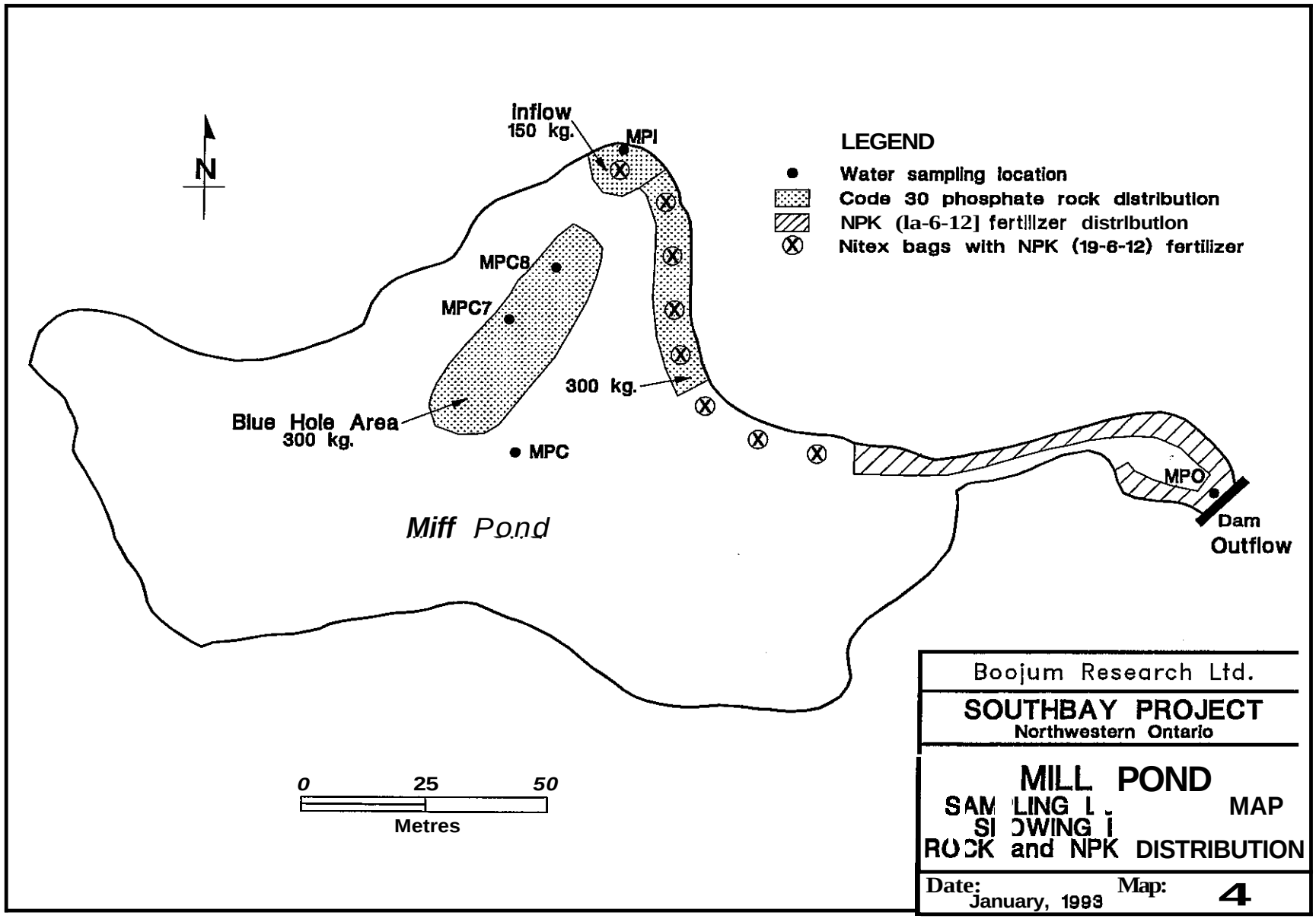
In conclusion, the estimates presented above were based on certain assumptions and field measurements of removal rates. These field measurements reflect wide variations inherent in dealing with natural ecosystems. However, using conservative values from the available data, the proposed Ecological Engineering approach will produce a balanced ecosystem capable of matching the annual contaminant loadings.

4. MILL POND

4.1 Introduction/History

Contaminant mobilization from the mill site is complex and difficult to quantify. Sources consist of unknown amounts of mine development rock and an unknown quantity of spilled and wind-distributed copper and zinc concentrate.

Analysis of data from a number of piezometers on the mill site indicates that ground water was moving both in the direction of Boomerang Lake and Confederation Lake. The ground water could potentially be driven by the water head in Mill Pond, and hence efforts were made to reduce contaminants in Mill Pond (Map **4).**



WW

South Bay 1992 Report
for: BP Resources

The concentrations of metals in Mill Pond in **1986** were extremely high, and only a very sparse algal populations could be seen along the west side of the pond. Nutrients and organic matter were added to plots on this beach on an experimental basis. Periphyton in Mill Pond noticeably responded to added amendments. A further experiment was carried out at the oufflow of Mill Pond to determine the adsorption capacity of sawdust for metals. These experiments were also promising, with high concentrations of metals found in sawdust and reductions of metals in the water.

Cattail transplant experiment results were not nearly as promising. Cattails were transplanted by several means, including hand-transplanting to sediments, transplant to floating mats and mechanical transplant of entire blocks of cattail rhizome and sediment. Although plants survived the first months following transplant, none survived beyond the first or the second year after transplant.

It was concluded that more adsorptive organic matter had to be placed into Mill Pond. Several truck loads of sawdust were distributed into Mill Pond, followed by several truck loads of hay in **1989.** These measures proved successful, indicated by an extensive algal population present by the summer of 1990.

Along with the addition of organics to Mill Pond, three retention ponds were constructed in the run-off area of Mill Pond (see Map 6, page 75). In these ponds, extensive vegetation and periphyton growth provides biological polishing, thus reducing the loading of metals and acidity to Boomerang Lake.

4.2 Long-Term Monitorina Trends

Mill Pond water has been intermittently sampled since 1977. During operations, large fluctuations in contaminant concentration data were noted, likely due to occasional liming, and irregular sampling. During demolition of the mine site, further changes in contaminant loadings were induced. By 1990, flows and contaminant loadings to the pond could be considered stable; monitoring data are summarized starting in this year, and up to 1992. The average pH at the outflow of Mill Pond was about 3.5 (Table 11).

Zinc concentrations in Mill Pond reached as high as 1000 mg L^{-1} in 1979, but have since stabilized in the last three years, and range from 200 to 300 mg L^{-1}. Sulphate concentrations in Mill Pond reached as high as 2700 mg L^{-1} in 1982, but have since declined, remaining within the range of 714 to 1815 mg L^{-1} over the last three years.

Acidity was only occasionally measured in Mill Pond until recently. Over the last three years, acidity has ranged from around 130 to a high of 820 mg L^{-1} $CaCO_3$ equiv. According to MOE data (Table 12), the acidities in 1991 and 1992 were the lowest recorded.

Iron concentrations varied widely in Mill Pond, ranging from 4 mg L^{-1} to 51 mg L^{-1} in the last three years. Since 1986, the time at which liming stopped, copper concentrations have decreased dramatically. For example, in 1986, copper concentrations as high as 95 mg L^{-1} were recorded. By 1992, the highest recorded concentration was 25 mg L^{-1}. This is a reduction of nearly 75 %.

'able 11: | ill Pond' ater San les

Date	23-06-90	16-06-90	11-10-90	16-05-91	25-06-91	26-07-91
Ass.#	1782	1805	2282	2669	2869	3013
Location	Mill Pond	Mill Pond Outflow	Mill Pond by Dam	Mill Pond Outflow	Mill Pond Near Qua	Mill Pond Weir-Top
Code	FA	FA	FA	FA	FA	FA
pH	2.4	2.7	3.66	3.8	3.6	3.08
Cond			2400	1390	820	1400
Cu	38	34	19	7.2	7.67	25
Fe	15	4.4	48	14.1	10	51
SO4	1566	1515	1386	714	810	1815
Zn	320	298	175	107	139	320
Date	26-07-91	13-07-92	13-07-92	18-07-92	14-08-92	16-10-92
Ass.#	3014	3841	3842	3848	4032	4240
Location	Mill Pond Weir-Bott	Mill Pond Outflow	Mill Pond Outflow	Mill Pond Outflow	Mill Pond Outflow	Mill Pond Outflow
Code	FA	FA	FA	FA	FA	FA
pH	3.12	3.25	3.17	3.65	3.69	3.34
Cond	1300	2100	2100	1650	1800	2320
Cu	21	25.2	23.1	14	14.3	26.1
Fe	32	18.9	10.2	18.6	36.8	15.5
SO4	1593	1497	1470	1170	1341	* 1440
Zn	282	329	308	233	191	278

* - determine | ɔy Boojun

Table 12: M)E Data n Mill Pond

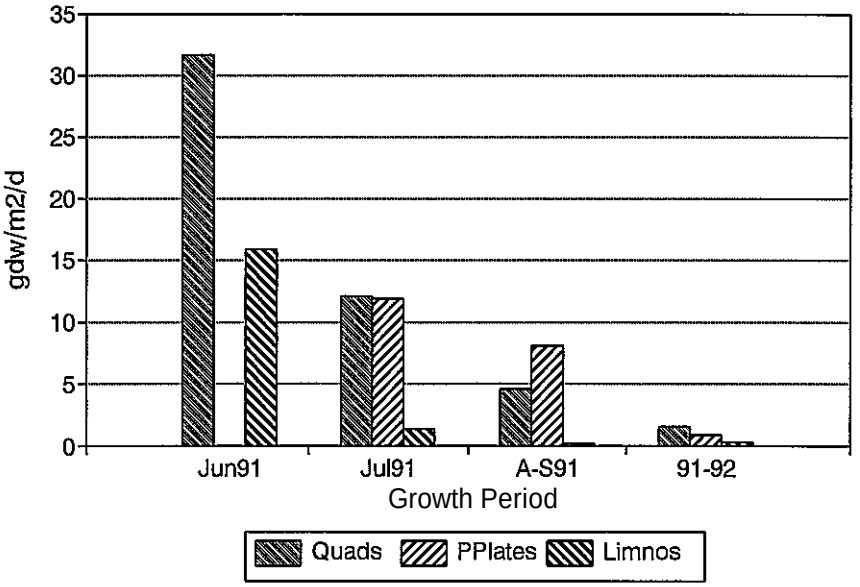
Location	SCode	Date	Zn mg/L			Acidity mg/L
Mill Pond	MPO	25-Oct-82	710			1398
Mill Pond	MPO	10-Apr-83	280			842
Mill Pond	MPO	12-Jun-84	580			1388
Mill Pond	MPO	17-Sep-84	330		2456	815
Mill Pond	MPO	28-Aug-85	600		2990	
Mill Pond	MPO	22-OCt-85	510		2953	1462
Mill Pond	MPO	16-OCt-89	400	3.0	2750	1306
Mill Pond	MPO	12-OCt-90	300	3.2	2655	
Mill Pond	MPO	16-May-91	97	3.4	803	185
Mill P RO	MPRO	16-May-91	22	4.9		41
Mill P RO	MPRO	16-May-91	62	3.8	479	128
Mill Pond	MPO	26-Aug-92	200	3.3	1377	368

4.3 Periphyton Growth Rates

Periphyton population expansion in Mill Pond commenced in 1990. Since then, the greatest population densities have been found in the narrow region just prior to the outflow of the pond, and below the pond in the area of Mill Pond Run-Off (Map 4). *Ulothrix* is the dominant periphyton species in narrow region and in the run-off area. These populations are coated with metal precipitates.

Growth of Mill Pond periphyton was measured in 1991 (Kalin and Wheeler 1992) and again in 1992. Three methods were used to quantify the growth. Large differences are noted between limnocorrals (enclosures), quadrats and periplates (horizontal artificial substrate). The highest growth rates were measured in the quadrats (Figure 9), where up to 32 gdw m^{-2} d^{-1} were estimated. As in Boomerang Lake, the biomass consisted not only of algal biomass, but a large amount of precipitates as well, despite utilization of the same washing procedure. Overall, the combined data from all method used to measure growth suggest that primary production in Mill Pond is high.

Fig. 9: Mill Pond Periphyton Growth Rates



The specific conditions for biological polishing in Mill Pond are quite different than in Boomerang Lake, where iron precipitate formation and sieving by PPC is the dominant process. In Mill Pond, periphyton are covered to a much less degree by iron precipitates, resulting in a different zinc polishing capacity.

The periphyton growing in the run-off area below Mill Pond are bright green, and contain 200 times less iron, but 100 times more zinc and twice as much copper, as periphyton growing directly in Mill Pond. Given that zinc concentrations in these populations are as high as 2 % of dry weight, Mill Pond area periphyton populations are contributing to biological polishing to a much larger degree than the Boomerang Lake population.

4.4 Biological Polishing Capacity

The growth rates determined from field experiments in Mill Pond were used to extrapolate the quantity of zinc which could be removed by biological polishing processes in Mill Pond. Growth rates are based on the surface area of the substrate, in this case, periplates and pond bottom. The same rationale was used for Mill Pond as was used for Boomerang Lake. The field growth rates are presented together with Boomerang Lake data in Table 9a. The minimum growth rates in this table were calculated using the average of the time-weighted growth rates plotted in Figure 9. The substrate surface area used was either one, or three, times the surface area of the pond.

Zinc concentrations in Mill Pond periphyton have been periodically determined since 1990. The periphyton sample with the highest zinc concentration was used as the maximum in Table 9a, and the average zinc concentration in periphyton collected in 1992 used as the minimum value. These represent the concentrations of zinc which can be sequestered in each gram of periphyton. By multiplying this concentration by

the primary productivity, a zinc removal rate is calculated. This is expressed in grams of zinc removed per day in the pond. By further multiplying this rate by the length of the growing season over which the periphyton would be expected to grow each year (150 days), the total concentration of zinc removed per year by periphyton can be estimated.

The zinc loading to Mill Pond from the mine site can be roughly estimated by calculating the base flow of just that portion of the drainage basin which flows into Mill Pond. This area was computed to be 5.2 ha. Using average annual precipitation data for the area, a base flow of 13,200 $m^3 a^{-1}$ is calculated for Mill Pond alone.

By multiplying this flow by the average concentration of zinc in Mill Pond in 1992, a zinc loading can be estimated. These calculations suggest that Mill Pond should have a zinc loading of around 3.5 tonnes per year. Comparing the annual zinc loads to that removed by periphyton, it can be seen that periphyton with a maximum growth rate, and growth surface area ratio of 3, would be able to remove 16 % of the zinc loading directly in Mill Pond. On the other hand, using minimum growth rates and a surface area ratio of 1, only 0.9 % of the zinc load would be removed.

In Figure 8, the data presented demonstrate that growth rates determined in the laboratory were stimulated with increasing light intensity and with the addition of fertilizer. Precipitates which accumulate on the surface of periphyton must block some light. Therefore, the growth rates of periphyton which do not harbour as much precipitate can be expected to be higher than PPC containing a large fraction of precipitate. For example, using the growth rates by precipitate-free algae in the laboratory of 7.3 % d^{-1}, and zinc concentrations of 20,000 $\mu g\ gdw^{-1}$, used in the calculations in Table 9b, it is possible that 135 % of the annual Mill Pond zinc loading would be removed.

To anticipate that biological polishing will be very effective in Mill Pond is not an unrealistic projection, as experiments with phosphate rock indicate that it will increase the pH and reduce the acidity, which in turn will result in a more active ARUM sediment in Mill Pond. A complete periphyton cover over the sediments in Mill pond will also reduce the quantity of suspended solids.

In summary, the biological polishing capacity estimated from the data collected to date is likely very conservative. The reductions in contaminant loadings from Mill Pond to Boomerang Lake will be significant in terms of the overall performance of the system.

5. DECANT POND

5.1 Introduction/History

In the first year of the project, an evaluation of the existing reclaimed tailings area was made, with respect to the longevity of the introduced vegetation cover. It was concluded that sufficient native species had started to colonize those areas where reclamation measures were successful. Areas covered by exposed gravel were sparsely populated by moss. From examination of pits dug into the tailings in **1990,** oxidation is primarily occurring in the vadose zone below the gravel / vegetation cover (Kalin et al. **1991).** The tailings cover was considered stable in the long term and no further measures were needed.

This was not the case for Decant Pond, where lime sludges in the pond bottom, containing high concentrations of zinc, needed to be stabilized. Acidic run-off evident along the tailings beach, if unabated, will likely cause Decant Pond to acidify in the long term, and subsequent re-solubilization of zinc would occur. Although extensive cattail populations were present along the perimeter dam forming a section of the Decant Pond shore, the tailings beach was void of cattails. This beach consists of natural muskeg, which re-emerged above the pond surface following the breach of the overflow dike when milling ceased in **1981.** Decant Pond received periodic lime additions, which were suspended when the Ecological Engineering project started.

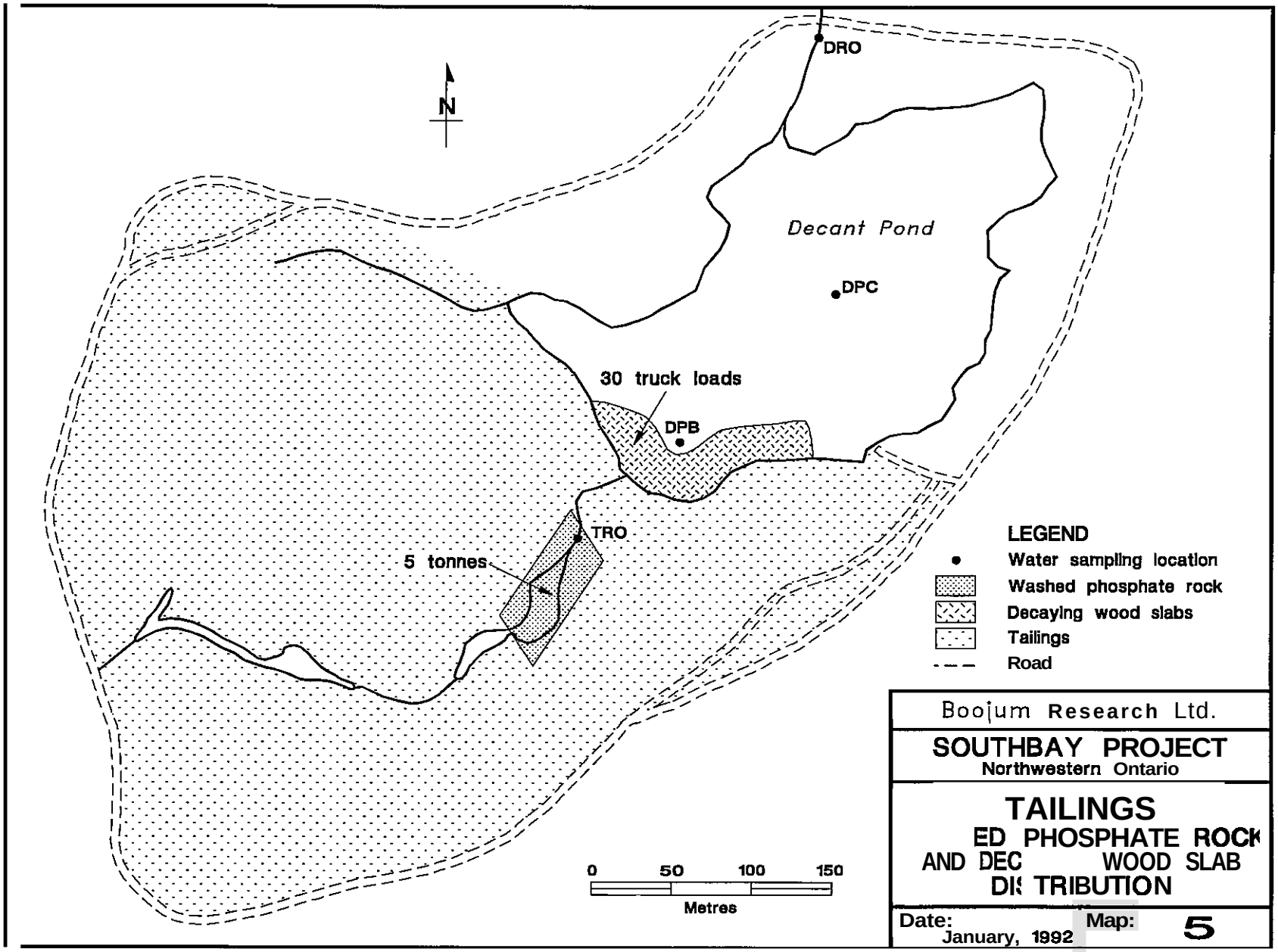
In **1986,** the pH of Decant Pond was **6.5** to 7.5, and populated by extensive periphyton mats. During studies of these populations, it was found that the biomass contained high concentrations of zinc. Periphyton mats grew on any available surface in the pond. Experiments were initiated to quantify the growth of periphyton. It was concluded that mine site demolishing material, which did not contain metals, i.e. wood, plaster, and insulation, provided excellent growth surfaces for the periphyton. Those

materials available from the demolition of the mill, mine and concentrator were used to scale up the periphyton growth in Decant Pond.

In addition, floating cattail mats were developed, which would provide further organic matter to sediments covering the hydroxide sludges. A total of 20 rafts of cattails were installed, providing the beginning of cattail islands. The water level in Decant Pond was raised slightly in 1990, to order to increase the cover of the cattail stands along the beaches. Although the overall cattail population has survived to date, Decant Pond became a habitat for muskrats, who consumed the floating cattails.

Several studies addressed the acid generation in the tailings. It was found that iron precipitation takes place as the water level fluctuates in the tailings mass. Most of the tailings deposit is subject to water fluctuations and generates acid. Measures were taken to install a barrier of reducing conditions (ARUM) along the acid generating tailings beach in 1992 (Map 5). The organic material used was decaying wood slabs, a byproduct of logging. This material had been tested in the laboratory for its suitability to stimulate microbial activity. Initially, these wood wastes will add organic acidity to Decant Pond, which may decrease the pH in the short term.

In 1992, water levels were very high and AMD remained ponded on the tailings during the entire summer. A coarse phosphate rock material was applied to the tailings to neutralize and remove iron in the ponded AMD before it flowed towards the ARUM reducing barrier (Map 5). The results of these measures can only be assessed over the next several years.


N
DRO
Decant Pond
DPC
30 truck loads
DPB
TRO
5 tonnes
LEGEND
Water sampling location
Washed phosphate rock
Decaying wood slabs
Tailings
Road
0
50
100
150
Metres
Boojum Research Ltd.
SOUTHBAY PROJECT
Northwestern Ontario
TAILINGS
ED PHOSPHATE ROCK
AND DEC WOOD SLAB
DIS TRIBUTION
Date:
January, 1992
Map:
5

5.2 Water Quality Trends

Decant Pond is about 340 m long and 186 m wide. It has a mean depth of 0.8 m. The pond covers an area of 4.4 ha, and has a volume of 37,700 cubic meters. Due to ground water flow and precipitation, the pond has an overflow of approximately 2.2 $L\ s^{-1}$. Map 5 shows locations of sampling stations, including DRO (Decant Run-Off), DPC (Decant Pond Centre) and DPB (Decant Pond Beach).

Although the pH of Decant Pond has been very variable, it was overall slightly lower in 1992 than previous years, probably due to higher inflow of acid from the ponds on the tailings and organic acid released by the wood wastes. The average, minimum and maximum values of zinc, pH, acidity, and sulphate concentrations are reported in Table 13 for the years of 1986 to 1992. The data were examined to determine whether there were any noticeable seasonal or long-term trends. Seasonal changes in the zinc concentrations are evident since 1988 (Figure 10) at DRO, the outflow; elevated zinc concentrations (> 10 $mg\ L^{-1}$) are restricted to spring and fall run-off.

Run-off from the tailings (TRO, Map 5) has contributed acidity to Decant Pond in 1991 and 1992. By plotting the difference in hydrogen ion concentration between samples collected on the same day at the tailings end of the pond near the source of surface AMD (DPB), and the outflow (DRO), it can be seen that DBP pHs were not significantly different from DRO, except in the last two years (Figure 11). This is additional evidence that acid pulses from the tailings, caused by high precipitation, contributed to the large ranges in sulphate, acidity, and zinc observed in Decant Pond.

Acidity in Decant Pond is directly related to the zinc concentration, as the pH is in that range where zinc starts to precipitate as its hydroxide. The correlation between these two parameters is excellent and indicates that, as zinc is removed by the periphyton during the summer months, acidity will also be controlled (Figure 12).

Table **13:** Decant Pond Concentrations, 1986 - 1992

	N	Average	Minimum	Maximum
Iron (mg/L)	30	0.5	0.01	3.9
Zinc (mg/L)	30	4.2	0.10	13.0
pH (units)	26	6.4	5.08	7.6
Acidity (mg/L)	11	25.0	11.50	40.0
Sulphate (mg/L)	20	353.8	64.50	588.0

Fig. 10: Decant Pond, 1986 - 1992
Seasonal Zinc Concentrations - DRO

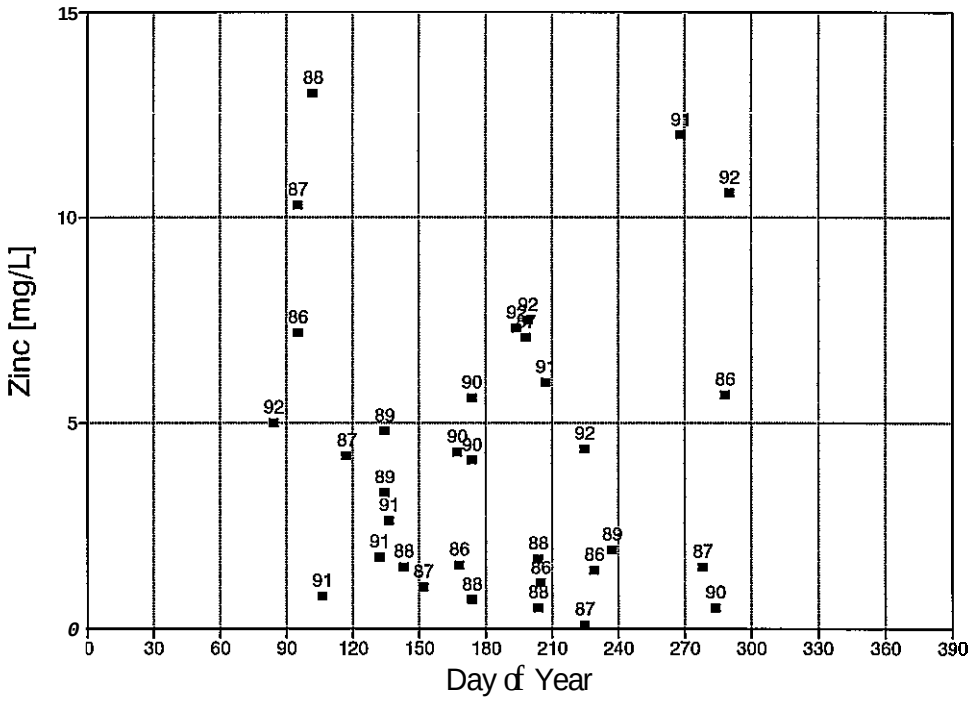


Fig. 11: Decant Pond
[H+], DPB - DRO

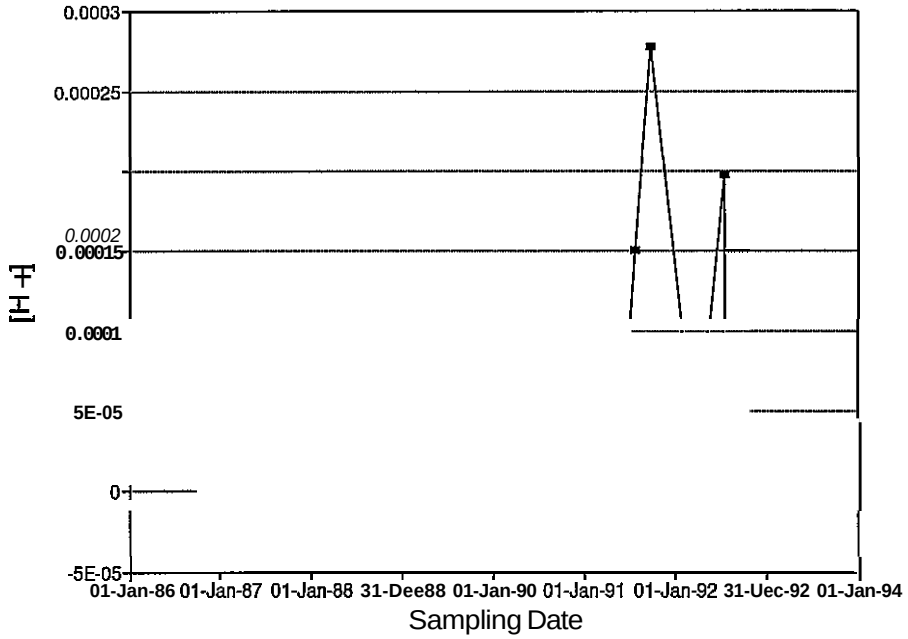
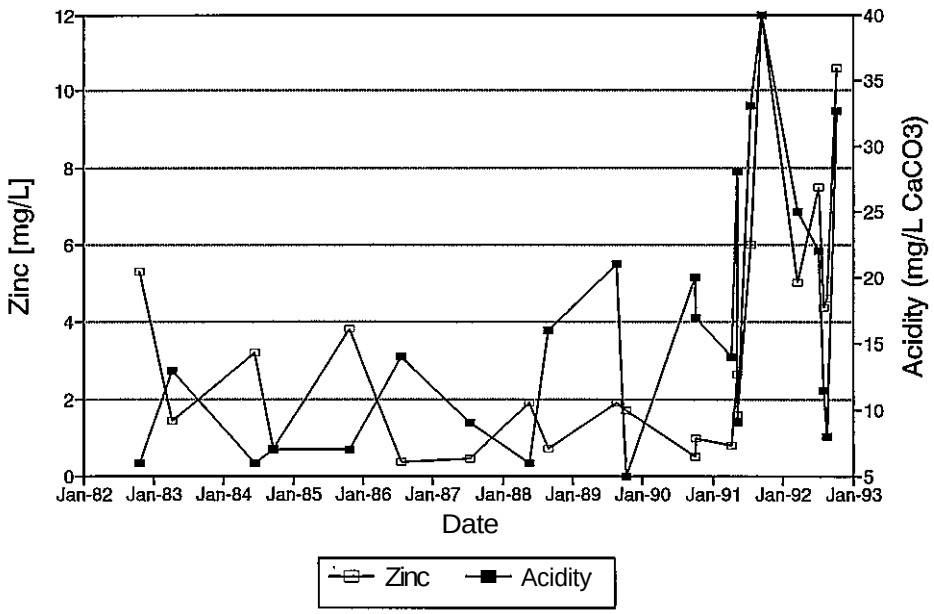


Fig. 12: Decant Pond
Acidity and Zinc (mg/L) 1982-1992



5.3 Biological Polishing Capacity

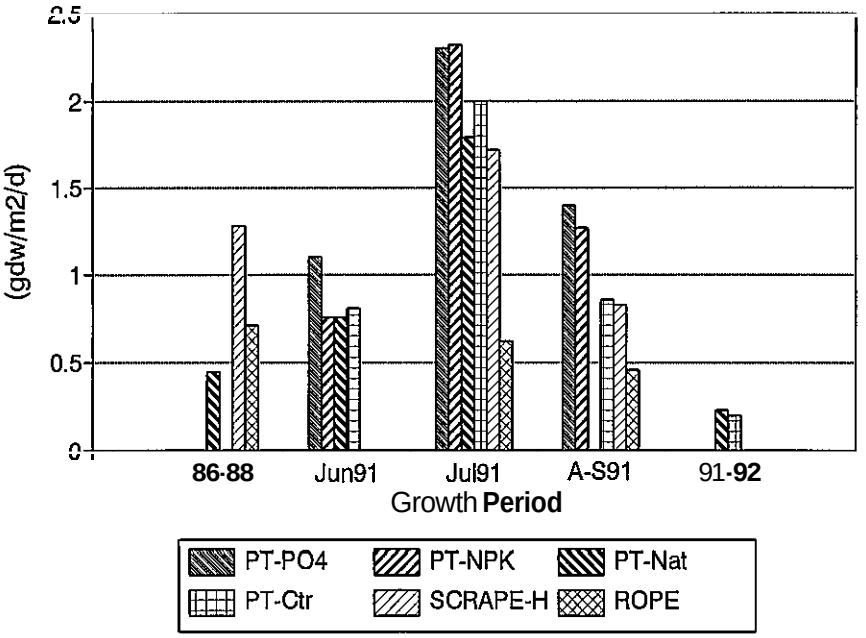
There are two distinct periphyton communities in Decant Pond. A *Ulothrix* community has recently started to dominate the periphyton flora on the western shore. Toward the middle of the pond, where pHs are more circum-neutral, a cyanobacterial (blue-green) community, dominated by *Oscillatoria*, forms dense mats. The periphyton mats contain only about 25-30 % organic matter, while the remainder is composed of precipitates.

Several methods were employed to measure periphyton mat productivity in Decant Pond. Peritraps were installed in the deepest area of the pond in 1991 and 1992. A second method involved removal of a known area of periphyton from submerged horizontal surfaces of wooden rafts. Finally, periphyton was harvested from polypropylene or cotton rope and quantified.

The results of all growth estimates are shown in Figure 13. Using Scrapings (Scrape-H) and peritrap nets (PT-) data, similar high growth estimates were calculated, compared to growth estimates using data from rope method. As expected, results indicate that the best growth rates (2.3 gdw periphyton m^{-2} (substrate) d^{-1}) were produced by periphyton growing in the presence of slow-release fertilizer in midsummer. Not only were growth rates high, but phosphorus levels in fertilized periphyton were also significantly higher than non-fertilized periphyton (data not shown).

The same approach was used as that described for Boomerang Lake and Mill Pond to extrapolate the quantity of zinc removed by a full-scale biological polishing process in Decant Pond. Growth rates presented are based on the surface area of the substrate, in this case, peritraps, ropes, and wood. Maximum growth rates shown in Table 9, are those calculated using July 1991 peritrap data. The minimum growth rates shown are calculated as the time-weighted average growth rate for all data presented.

Fig. 13: Decant Pond Periphyton
Growth Rates



Zinc concentrations in periphyton from Decant Pond have been determined periodically since 1987. The periphyton sample with the highest zinc, and the average zinc concentration in periphyton collected in 1992, are shown as min/max values.

Using the maximum growth rates, and assuming substrate surface areas equivalent or three times greater than Decant Pond's surface area, the estimated contaminant removal rates by periphyton in Decant Pond are extremely (and unrealistically) high (Table 9a). These calculations suggest that periphyton would be able to remove 209 times the projected zinc loading. Even when the minimum growth estimates and a substrate surface area equal to the area of Decant Pond are used, 95 %, or near complete, to 285 % removal *of* the annual zinc concentrations are estimated.

While it is, of course not possible that periphyton remove more zinc each year than the annual loading, these calculations demonstrate that if the periphyton population expanded over area equivalent to Decant Ponds area, and maintained at least the minimum growth rates estimated, then most *of* the annual zinc loading would be

removed. Of course, as zinc concentrations in Decant Pond diminish, zinc accumulated in the periphyton biomass cannot be expected to remain at currently high concentrations, but to diminish as the supply available in Decant Pond water diminishes. Meanwhile, for the periphyton population to maintain the minimum growth rate as it expands to cover a surface area equivalent to Decant Pond will require an adequate supply of nitrogen and particularly phosphorus. Promotion of periphyton growth following the application of natural phosphate rock on the tailings beach should be observed in the 1993 growing season.

6. ESTABLISHMENT OF THE NEW ECOSYSTEM

6.1 Introduction

In the previous sections, estimates of the annual contaminant loadings and the capacity of the biological polishing system were made. The self-sustaining, long-term solution to the decommissioning of the site, which is to be achieved with Ecological Engineering, has at its core the objective to achieve contaminant removal rates equal to or exceeding contaminant release rates. From the results obtained so far, the annual loadings of zinc and iron can be counteracted by biological polishing once the new ecosystem is fully established. Since a large fraction of run-off entering Boomerang Lake contains elevated concentrations of sulphate and hydrogen ions, microbially-active ARUM sediments are required to generate alkalinity and consume sulphate.

In Boomerang Lake, contaminants have been accumulating for a number years. Boomerang Lake currently harbours metals and acidity which has accumulated in the last three years; this load has to be removed, so that annual loadings need only be dealt with by biological polishing and ARUM, the latter through alkalinity generation. A one-application measure must be identified which can remove this backlog of contaminants, but which is also compatible with and, ideally, beneficial to, both biological polishing and ARUM processes.

Application of lime would not meet these requirements, since lime would have to be applied for an entire year, generating sludges which would cover the sediments. This would reduce the rate of exchange of ions between the water and sediment, thereby inhibiting ARUM sediment processes. In addition, lime would scavenge much of the phosphate in Boomerang Lake water, while providing no other nutrients. Clearly, an alternative one-time treatment is required, providing, ideally, plant nutrients to the water and sediments to initiate nutrient cycling.

In 1992, work was initiated with phosphate rock, which contains phosphatic carbonate, examining whether this material can neutralize acidic water and provide nutrients on a slow-release basis. In addition, organic carbon, necessary for ARUM development, was tested in the lab, then added on a large scale to Decant Pond beach in 1992. The results of these two topics are presented in Sections 6.2 and 6.3, respectively.

6.2 Phosphate Rock

Phosphate rock is mined by Texasgulf and sold in several different grain sizes, for application as a fertilizer for acidic soils. Phosphate rock was tested in Boomerang Lake, Mill Pond and on tailings areas in July 1992. After application of the rock, water and sediments were sampled for chemical analysis. In general, the field tests were promising and will facilitate estimates for the anticipated one-time application. The results are discussed for each of the water bodies.

6.2.1 Mill Pond

Phosphate sand (Code 30; 30% phosphate, mesh 65 to 200) was applied in Mill Pond. Based on bench-scale laboratory tests, this mesh size would react relatively slowly and contain sufficient phosphate to effectively reduce acidity and supply phosphate through to the spring of 1993. Distribution locations are shown in Map **4.** Approximately 300 kg were placed at locations MPC 7 and MPC 8, and another 300 kg were distributed along the eastern shore of Mill Pond. In addition, about 150 kg were put into the inflow areas of the pond, and 55 kg of slow-release 19-6-12 fertilizer (NPK; Osmocote) were distributed along the eastern shore in the area around the phosphate rock. Twenty kg was also broadcast into the outfall area of the pond, where an extensive periphyton population had already established. In the spring of 1993, the fertilizer and phosphate sand will be collected, and analyzed for remaining phosphate content.

Water samples were taken from stations MPC, MPC 7, MPC 8 and at the oufflow (MPO) before and after the application of sand. Acidity, dissolved phosphate, pH, conductivity, Em (Redox), and temperature were measured daily for 3 days after the addition of rock. The results of water and sediment samples analyzed by ICP are reported in Appendix E.

In Figure 14a, the concentrations of Al, Cu, Fe, and acidity plotted for the MPC samples collected before (July 13) and after (July 16) the application of phosphate rock Code 30. The two elements which showed the largest decrease were, as expected, iron and aluminium. The differences in water chemistry, after one day, were not as pronounced as those measured three days after the application. The results are, overall, very encouraging.

The results for station MPC 7 are plotted in Figure 14b. This sampling location is located in a depression where Mill Pond is deepest, and where less mixing and a greater effect by phosphate rock could be expected. Results show a pronounced difference in water quality, before and after the phosphate application.

Fig. 14a: Mill Pond - Centre
Before and After Phosphate Rock

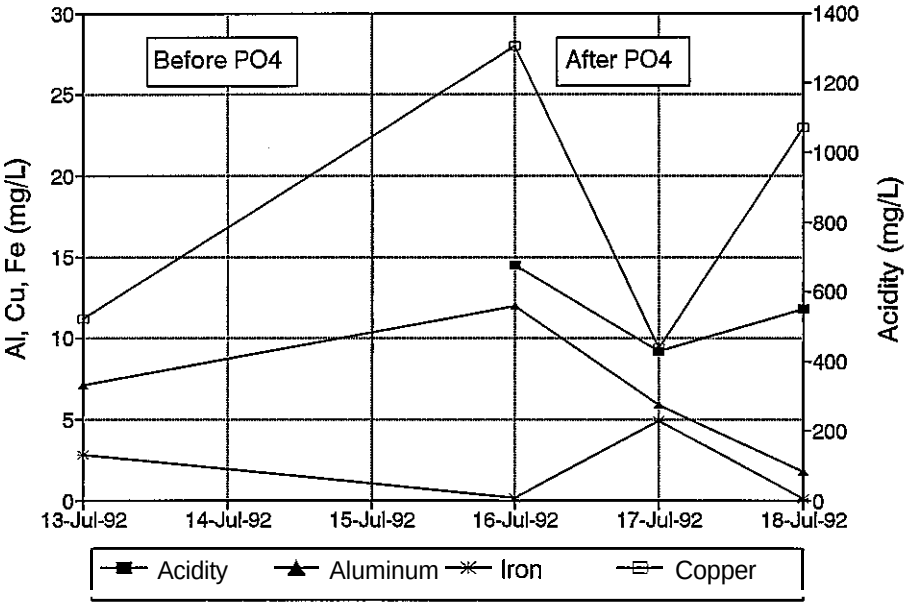
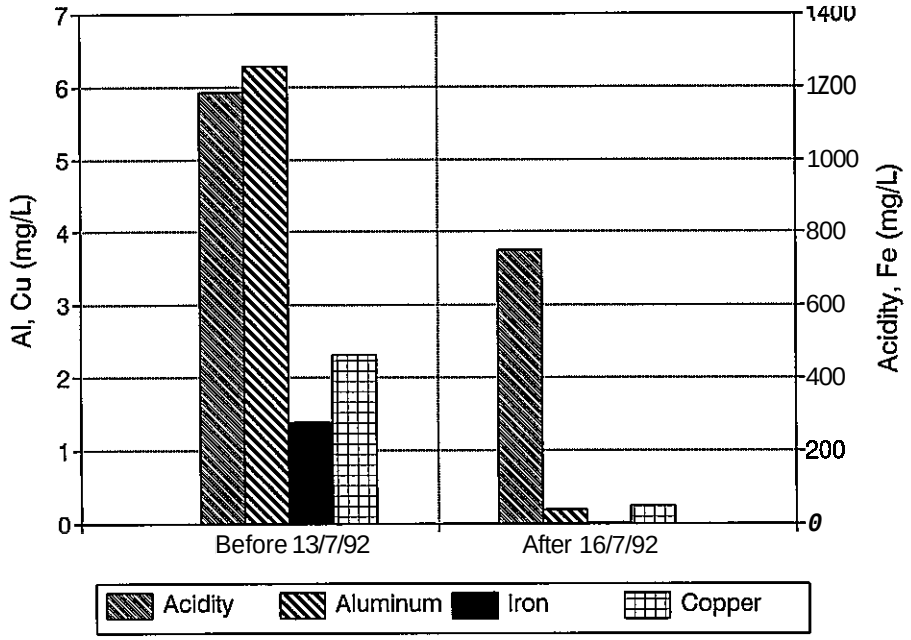


Fig. 14b: Mill Pond - Station 7
Before and After Phosphate Rock



6.2.2 Tailings/Decant Pond

Five tons of phosphate rock (waste gravel; 21 % phosphate, -6 to 14 mesh) was distributed in small AMD ponds which had accumulated on the tailings, due to the high water levels (Map 5). Because phosphate rock was distributed with a back-hoe, a somewhat irregular distribution pattern resulted. Water samples were taken from the tailings run-off area several hours after the initial placement, and each day following for 3 days. Water was also sampled 1 month and 3 months later.

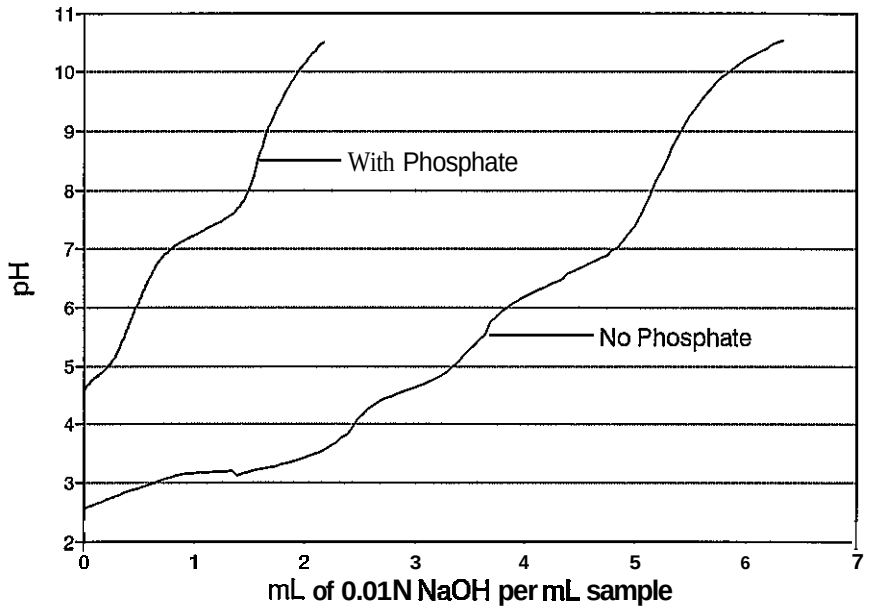
Water chemistry of samples collected above and below the area where phosphate rock was distributed are presented in Table 14. Large fractions of the iron and aluminium were still being removed after three months. The course material reacted very quickly to the high acidity water (Figure 15). The initial reactions are likely attributable to carbonate in the material.

The most important characteristic of phosphate rock in the current application is the duration of activity, rather than the specific rate at which it reacts. In fact, after 3 months, the material was still reacting. If limestone were used, it would have fouled within one week of placement.

Table 14: Water Analysis in Tailings Area, (mg/L)

Runoff	File	Date	Acidity	Al	Fe
Before PR	3861	16-Jul-92	580	34.3	53.5
After PR	3865	18-Jul-92	410	5.19	12.9
Pre PR	4033	13-Aug-92	2620	96.5	552.0
Post PR	4034	13-Aug-92	798	57.5	1.3
Pre PR	4237	17-Oct-92	2588	45.7	648.0
Post PR	4238	17-Oct-92	717	29.8	25.9

Fig. 15: Tailings Runoff Water
Sampled on **Aug. 14,1992**



One month after application, some of the reacted phosphate gravel was collected. The gravel was washed with water to remove loose precipitates. From 438 g phosphate gravel, 13 g of precipitate were obtained. The weight ratio of precipitates to phosphate gravel was 3.0 %.

Both Precipitates and washed gravel were dried at 110°C for 24 hours. Both the original and reacted, washed gravel were ground into powder and analyzed by ICP. The results are shown in Table **15.**

Aluminum and iron were the largest components in the precipitates, which corresponds with observed removal of these same elements from water following contact with phosphate rock. The reacted, washed rock contained Al, Fe, S and Zn in the same concentrations as the original, un-reacted rock. The reacted phosphate rock still contained 94 % of its original phosphate, available for further reactions.

	File	Al	Ca	cu	Fe	P	S	Zn
Original rock	4083	5500	311000	99	6660	89200	12200	1320
Washed rock	4074	6040	310000	92	7390	84200	12700	1110
Precipitate	4073	70700	32200	1460	193000	23300	30600	6290

6.2.3 Boomerang Lake

Nine tons of phosphate rock (code 31; 31 % phosphate, 200 to -200 mesh) were distributed over specific areas in Boomerang Lake (Map 3). A total of 5.5 tons were spread in the vicinity of B9 to B10, 3 tons were distributed between B2 and B11, and 0.5 t were distributed in the vicinity of B7 (see Map 3).

The B9 - B10 area was chosen for phosphate rock distribution based on a conductivity survey, including bottom sediments, along the suspected tailings seepage area. The transect data are presented in Appendix E. Generally, the conductivity on the bottom ranged from 400 to 600 μmhos cm^{-2}. Elevated conductivities ranging from 1020 to 1600 μmhos cm^{-2} were found in stations 8, 10, 12, 13, 14, 19, 5, 6, and 7. Therefore, the transect areas with the high conductivities were targeted for the phosphate application (see Map 3).

Water samples were taken from B2, B7, B9, and B11 before phosphate addition, and at B2, B7 and B9 after distribution. Water samples were also taken 1 and 3 months after phosphate application. Sediment samples were collected from B2, B7 and B9, before and after application.

In Boomerang Lake, the major elements contributing to acidity are aluminum and iron. When Fe and Al salts dissolve in water, they hydrolyse and release hydrogen ions:

$$Al^{+3} + H_2O = Al(OH)^{+2} + H^+$$
$$Al(OH)^{+2} + H_2O = Al(OH)_2^{+} + H^+$$
$$Al(OH)_2^{+} + H_2O = Al(OH)_3 + H^+$$

$$Fe^{+3} + H_2O = Fe(OH)^{+2} + H^+$$
$$Fe(OH)^{+2} + H_2O = Fe(OH)_2^{+} + H^+$$
$$Fe(OH)_2^{+} + H_2O = Fe(OH)_3 + H^+$$

Theoretically, phosphate, added to Boomerang Lake water, should have precipitated with Al^{+3} and Fe^{+3} and associated with hydrogen ions.

$$PO_4^{-3} + Al^{+3} = AlPO_4$$
$$PO_4^{-3} + Fe^{+3} = FePO_4$$
$$PO_4^{-3} + H^+ = HPO_4^{-2}$$
$$HPO_4^{-2} + H^+ = H_2PO_4^-$$
$$H_2PO_4^- + H^+ = H_3PO_4$$

When phosphate rock was applied in Boomerang Lake, large, quantities of precipitates were visible in the water. Water appeared “milky“ and remained so for several days. Just beyond the outflow of Boomerang Lake, station C1, the phosphate concentrations were monitored, since the intent was to relegate phosphate as a precipitate to the sediments, and not allow it to leave the Lake. Concentrations at the oufflow remained

below the detection limit of < 1 mg L^{-1} for three days after the application. Therefore, it is reasonable to assume that all the phosphate remained in the lake.

In Figure **16,** the pH, acidity, and concentrations of Al, Fe, Mn and Zn in water collected before and after phosphate treatment are plotted. While no differences can be noted in surface water samples, large differences in aluminum, iron, sulphur and zinc were apparent in bottom water samples. Since the phosphate rock particles sank to the bottom, little time was available for reactions in the water column. Long term reactivity of phosphate rock can be expected to operate at the sediment surface. Since metal analyses are based on filtered, acidified samples, precipitated metals were not measured. The precipitate content of the sediments, however, should increase over the same time period. Metal concentrations in sediments (as solid samples) collected after phosphate treatment were considerably higher than in sediments collected before phosphate rock application (Figure **17).**

Fig. **16:** Boomerang Lake Water
Before and After Phosphate Treatment

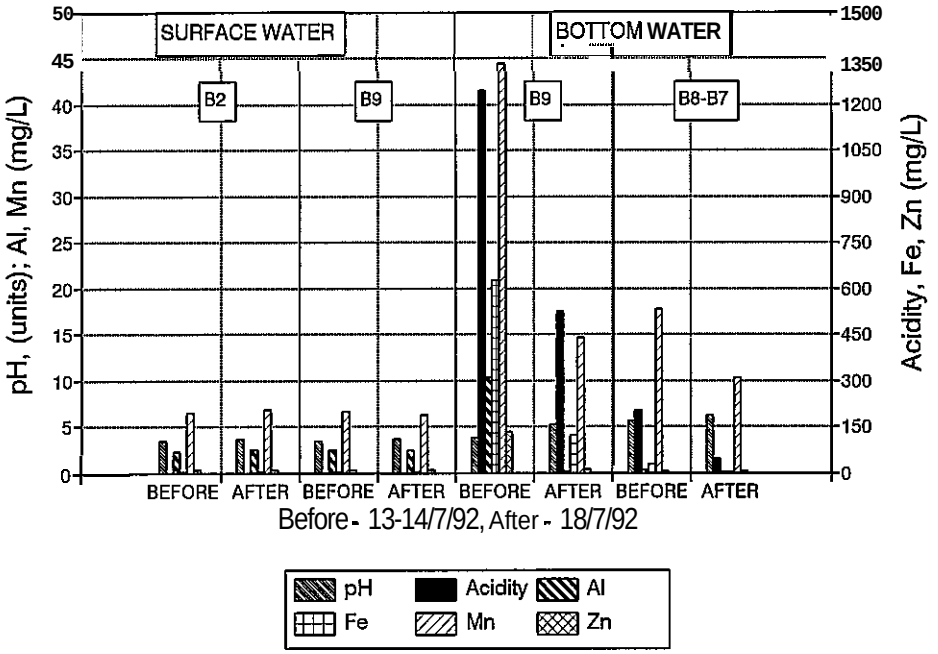
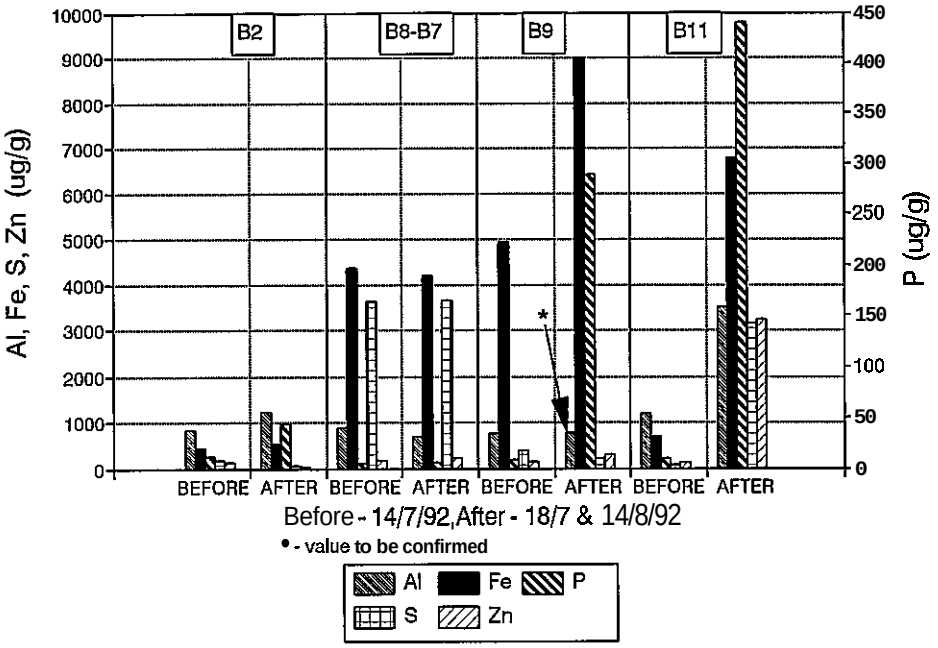


Fig. 17: Boomerang Lake Sediment
Before and After Phosphate Treatment



Although metals were precipitated by the phosphate treatment, the question remains concerning how much of the lake's metal loading was in fact removed. The sediment concentrations of precipitated aluminium, zinc and iron after the phosphate rock treatment (μg gdw^{-1}) were converted to mass of metal per unit of lake bottom, using a sediment water content of 80%. This was multiplied by the lake area over which the phosphate was broadcast. The gives an estimate of the amounts of metals removed with the phosphate rock application. The total volume of water into which phosphate powder was distributed was 42,000 m^3, resulting in an application rate of approximately 214 mg PO, rock L^{-1}.

The 9 t of phosphate rock application resulted in the removal of 330 kg of zinc, 1.35 tonnes of iron, and 276 kg of aluminum from the water. These amounts are equivalent to lake concentration decreases of 6 % for dissolved zinc, 74 % for iron, and 10 % decrease for aluminum, within two days following application.

The level of microbial activity in Boomerang Lake sediments is the final component which has to be addressed. Some preliminary results from laboratory work with sediments are presented in Table 16a and 16b. The sediments were collected with an Eckman grab sampler. Since this technique inherently disturbs the sediment stratification and mixes sediment with some overlying water, the sediments were allowed to settle in jars in the laboratory. The pH and Em (Redox) were measured, and zinc and phosphate concentrations determined in the sediments and overlying water (Table 16a, 16b). After several months storage in the lab, pore water pHs at B2, B9 and B11 were low, suggesting sediments had oxidized. The acidity was likely related to the high concentrations of Al and Fe in the sediment.

Table 16a: Chemistry of Water Overlying Sediments Collected from Boomerang L., Aug-Oct 1992

Station Sampled	B2 July-14	B2 July-18	B2 Oct-17	B1 Aug-14	B11 July-14	B11 Aug-13	B11 Oct-17
pH	4.75	5.23	4.75	4.54	3.74-3.42	5.07	4.48
PO4	2.9	5.3	3.77	-	2.6	-	2.84
Zn	0	88	18.75	15	0	105	33.75
Acidity	34	105	64.5	165	76.5-365	440	109

Station Sampled	B8 July-14	B7 July-18	B8 Oct-17	B5 July-14	B4 July-14	B4 Oct-17
pH	5.59	6.25-6.69	3.65	6.29	5.28	5.43
PO4	3.2	2.8	7.08	2.2	2.6	3.15
Zn	0	0	52.5	0	0	4.5
Acidity	190	39.5-56	413.4	46	58.5	18.9

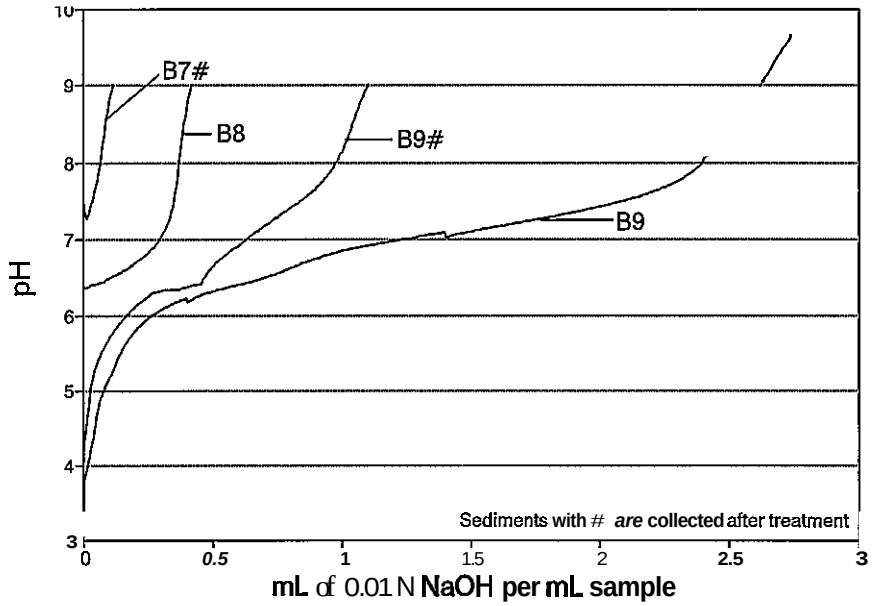
Table 16b: Chemistry of Water Overlying Sediments Collected from Boomerang L., Jan 1993

Station Sampled	B2 July-14	B2 July-18	B2 Oct-17	B1 Aug-14	B11 July-14	B11 Aug-13	B11 Oct-17
pH	5.19	5.95	3.51	5.06	6.35	3.78	3.38
Eh*	-108	-109	112	-54	-232	346	203
PO4	0.53	-	0.45		0.35	-	0.6
Zn	0.61	-	46.1		1	-	173
Fe	0.16	-	16		5.4	-	29.8
LOI%	2.35	2.1	8.98	2.8	3.67	2.91	5.52
Fe(sedi)	443	532		484	675	6790	
ICP No.	4199	4195		4200	4204	4079	

Station Sampled	B8 July-14	B7 July-18	B8 Oct-17	B5 July-14	B4 July-14	B4 Oct-17
pH	6.17	4.62	2.97	6.22	5.89	4.05
Eh*	-132	205	171	-199	-102	143
PO4	0.37	0.2	0.99	0.29	0.37	2.53
Zn	0.23	12.3	346.1	0.3	1.15	23
Fe	34.8	0.13	181.9	24	0.24	16
LOI%	8.33	5.98	4.43	30	30.9	32.8
Fe(sedi)	4370	4180		847	857	
ICP No.	4196	4201		4197	4198	

Sediment pore water acidity titrations, for the sediments sampled before and after the phosphate application, are shown in Figure 18. From the curves, it can be determined that acidity of sediment pore water noticeably decreased in those sediments which were collected after phosphate treatment. In October, the sediments were remeasured. The pH of the samples collected in July had increased, while all the later samples (B2, B11 and B4) showed lower pHs, and higher zinc and iron concentrations.

Fig.18: Boomerang L Sediment Pore Water
Sampled July 14 - July **18,** 1992



When all the sediment-related waters were compared with respect to pH, Em and [Fe], at different times and stations, it was noted that water with low pH was always related with higher Em and higher iron concentrations. This illustrates, again, that pH changes are mainly controlled by the iron oxidation and hydrolysation in these sediment waters. Redox conditions in the small volume of sediments in jars were not low enough to retain the metals in the sediments.

There is some indication that the pH decreases in sediments which contained lower amounts of iron (400-800 μg gdw^{-1}) were not as great as in sediments with more iron (> 4000 μg gdw^{-1}). However, one exception is sediment collected at B8 (July 14, 1992),

which contained a high concentration of iron (Fe=4370 μg gdw^{-1}), but a low organic content (LOI=8.33%). After several months in the lab, this sediment's Em was still low (-132 mV), and the pH neutral.

Two other samples, B9 (July 14, 1992) and B9 (July 18, 1992), also contained high concentrations of iron (Fe=4940 and 9010 μg gdw^{-1}). Their LOIs were also very low, 6.45 % and 10.35 %, respectively. After several months, Ems were still low (-21 and -217 mV), but pHs had dropped to 3.99 and 3.43, respectively. Sediments with phosphate, B9 (July 18, 1992), were distinctly different from sediments without phosphate, B9 (July 14, 1993).

These very preliminary observations do suggest that the laboratory techniques used were not effective in terms of gaining a full understanding the dynamics of sediment redox conditions in Boomerang Lake. An Eh survey of the organic sediments should be carried out to determine the *in situ* redox dynamics. The sediment/water interface redox dynamics are complex, but an understanding of them is necessary to quantify metal and acid fluxes between the sediment and overlying water.

The effects of applying phosphate rock upon water quality have to be considered separately from effects on sediment chemistry. Because phosphate is readily adsorbed onto iron precipitates, iron is the principal variable determining the phosphorus flux at the sediment-water interface. The low phosphate concentrations measured in the sediment pore waters is evidence of this process of phosphate adsorption by iron in the sediment water.

Metal release from the sediments is related to the redox state of the sediments, the organic matter content, and phosphorus and oxygen concentrations in sediments. In sediments, metals are chelated with organic matter, or precipitated with phosphates.

Under aerobic conditions, rapid degradation of organic matter, and subsequent release of metals from organics occurs. However, these released metals, especially iron, can in turn precipitate with phosphate and remain fixed in the sediments.

Under anaerobic conditions, ferric iron is reduced to ferrous iron, and the more soluble ferrous phosphate may flux from the sediment into the overlying water. However, with slow degradation of organic matter under these anaerobic conditions, a higher concentration of metals can remain chelated. Overall, if anaerobic, reducing sediments have a high organic content, and are overlaid by an oxidized sediment layer containing adequate phosphate, metal release from sediments may be minimized. These are the required sediment conditions in Boomerang Lake, Mill Pond, and Decant Pond.

In Boomerang Lake, the organic content (based on % LOI) ranged from 2.1 to 32.8 %. In Confederation Lake the LOIs are similar, ranging from 1.1 to 63 % organic matter, with a mean of 23 %. Additions of organic matter might be required in some areas of the Boomerang Lake. Organic amendments have been made to Mill Pond and Decant Pond beach. Thus, to initiate ARUM activity, several experiments were carried out prior to placement of wood waste onto the Decant Pond beach.

Enhancement of ARUM, a natural microbiological process, has been tested by Boojum Research for the amelioration of AMD. The process consists of stimulating the development of an anaerobic microbial community in reducing sediments which, through bacterial metabolic activity, reduces sulphate to sulphide, precipitates metals, and raises pH. Feeding these bacteria the proper mix of organic carbon and other nutrients enhances their activity, so that larger volumes of AMD can be treated.

6.3 ARUM in Decant Pond Tailings Beach Sediments

Sporadic run-off from the tailings into Decant Pond contains high concentrations of zinc and iron. Because this run-off contributes a appreciable amount of acidity and metals to the Decant Pond, pro-active ameliorative measures needed to be taken.

In 1988, hay bales were spread along the beach area in order to stimulate the ARUM bacterial community (Acid Reduction Using Microbiology). At that time, however, little was known of the specific nutritional requirements of the ARUM bacterial community, and an insufficient quantity of material was distributed. With the benefit of 5 years additional experience and experimentation, the ameliorative measures were taken to initiate ARUM on the Decant Pond Beach described in the following section.

6.3.1 Methods and Materials.

A laboratory experiment was conducted examining amendments which stimulate ARUM microbial activity in four litre jars of Decant Pond water, as well as Boomerang Lake and Mill Pond water. Treatments included alfalfa, decomposing 30 year old forestry wood slab waste from the South Bay area, and Osmocote fertilizer.

The experiment showed that bacterial sulphate reducing activity was present in all the jars amended with wood waste, and zinc and sulphate concentrations decreased (Figures 19, 20). The addition of slow-release fertilizer did not show any enhancement of the ARUM process. From this experiment, it appeared that the wood wastes may be a suitable material to initiate ARUM activity along the Decant Pond beach.

Fig.19: Boomerang Lake Wood Experiment
from Nov.23,1991 to April **23, 1992**

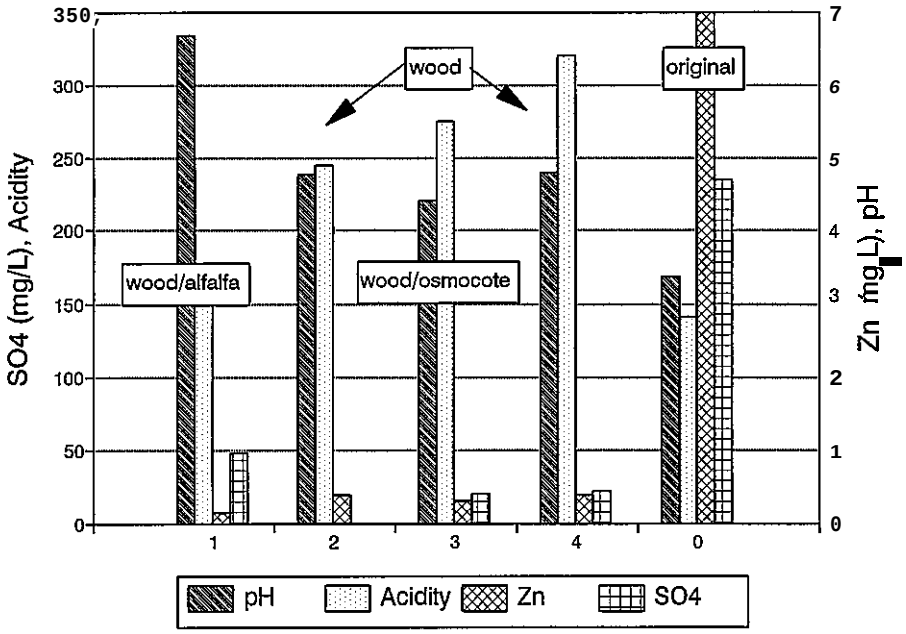
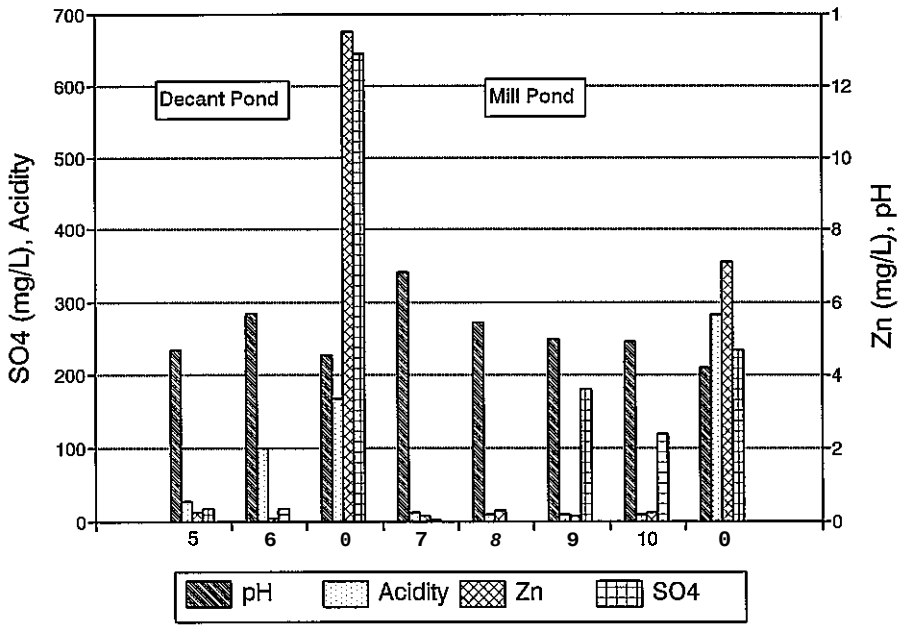


Fig. 20: Decant & Mill Pond -Wood Expt
from Nov.23,1991 to April **23, 1992**



After permits were received to use this material, 30 dump truck loads of wood waste were piled in and around the beach area of Decant Pond in early July, 1992. Water samples were taken in pools among the slabs of wood waste. Additional sampling was performed one and three months after set-up.

There were no significant elemental changes in water samples from the beach before and after wood placement. However, water pH increased in all the samples after wood waste placement, except those collected from within the wood pile. This phenomenon was still evident after 1 and 3 months. These results are only preliminary, and further sampling for determination of surface and pore water chemistry in the wood waste field must performed in 1993.

7. MINE SITE

7.1 Overview

Piezometers were installed during the hydrological investigations of the entire mine site (Map 6). Possible ground water flows towards both Boomerang Lake and Confederation Lake (M18 and M38) were addressed. Ground water flow velocities towards Confederation lake ranged from 2.5 m a^{-1} to 4.6 m a^{-1} for the Backfill raise area (M18) pathway, and for the Mill site pathway, velocities ranged from 6.5 to 9.0 m a^{-1} (M38).

Contaminated water was predicted to arrive at Confederation Lake in 21 to 40 years. As Mill Pond was suspected of being the driving force for the water flowing through M38, work was initiated to divert fresh water away from Mill Pond, reducing the head driving water through the contaminated Backfill Raise drainage basin.

These remedial measures were taken without knowledge of degree of flooding in the underground mine workings. If water levels in the working further increased, these new levels could potentially result in significant alterations to the mine site hydrological conditions. Hence, the typically transient seepages from the Portal Raise and the Backfill Raise area were monitored annually. In the fall field trip in 1991, increased flows were noted from both the transient seepages. Water samples were collected at that time for chemical analysis.

The historical data are presented up to 1991 in Table 17. Although the sampling locations and sampling intervals were inconsistent, the diversion ditch constructed in 1989 generally appeared to diverting a significant zinc loading to Boomerang Lake, and away from Confederation Lake. For example, 101 mg zinc L^{-1} were present in water leaving the mine site at station BR1A in July, 1991.

Boojum Research Ltd.
SOUTHBAY PROJECT
Northwestern Ontario
MILL SITE
SAMPLING LOCATION
MAP
Date: Nov/92
Revised:
Map#: 6
LEGEND
Water sampling location
Piezometer sampling location
LOWER DAM
UPPER DAM
DAVE'S DAM
Metres
Feet
0
50
100
150
200
250
300
450
600
BR2.5
BR3
BR3.5
BR4
BR5
BR1A
WHNP
WHSP
BRC
BRP
M18
BR18
BR13B
BR13
B13C
PRC
PRS
CS13
C13
C8
CON
MP1
MPC8
MPC7
MPC
MP3
MPOT
M38
M13
M5
M15
M12
M14
MPRH

Table 17: Backfill Raise Historical Data, 1987-1991

Date	Ass.#	Location	Ca	Cu	Fe	Mg	S	Zn	pH
13-Jul-87	4	BR5	51	0.5	<0.01	10.4	59	<0.01	
13-Jul-87	8	BR2.5	13	0.2	<0.01	4.3	8	<0.01	
15-Jul-87	12	BRP	363	0.7	83	54	661	119	3.00
13-Jul-87	17	BR3	34	0.5	3.5	9.6	43	<0.01	
13-Jul-87	25	BRIA	74	0.5	107	24	252	14.8	
12-Aug-87	117	BRIA	57	0.01	0.6	9.9	66	2.5	3.60
12-Aug-87	118	BR3	28	0.01	0.1	6.2	29	0.1	
12-Aug-87	119	BR5	27	0.02	0.7	9.7	<0.01	<0.01	
12-Aug-87	120	BRP	65	0.5	17	11	149	11	4.54
05-Oct-87	168	BR1A	76	0.5	9	14	127	18	3.35
05-Oct-87	169	BR3.5	32	<0.01	<0.01	7	27	0.4	6.34
05-Oct-89	175	BR5	112	0.1	<0.01	17	113	7.2	5.87
08-Apr-88	304	BRP	17	0.06	1	3.1	23	4.1	
19-Jun-88	471	BR4	20	-0.01	0.1	3.7	14	0.7	
20-Jun-88	504	BR2.5	22	0.01	0.7	4.2	36	3.6	
14-May-89	1024	BR18	284	10	58	58	653	249	3.28
14-May-89	1035	BR4	38	1.4	72	11	169	20	3.02
14-May-89	1040	BR13C	466	5.9	9.3	125	1258	881	5.60
25-Aug-89	1285	BR18	182	0.1	0.5	17	189	1.3	3.52
23-Jun-90	1790	BR18	260	0.7	29	41	380	128	4.20
16-May-91	2656	BR3	99	0.24	30.3	20.5	223	96.9	3.10
16-May-91	2660	BR18	242	0.76	9.8	41.7	346	81	3.50
25-Jun-91	2867	BR13	321	6.22	47.2	79.4	689	295	3.00
25-Jun-91	2868	BR18	195	0.78	8	39.5	280	96.2	3.22
26-Jul-91	3004	BR4	57	<1	21	15	145	39	2.95
26-Jul-91	3005	BR1A	106	2	88	26	334	101	2.62
26-Jul-91	3006	BR18	232	<1	9	40	283	73	3.56
26-Jul-91	3007	BR13	318	<1	44	63	462	199	3.14
25-Sep-91	3449	BR18	255	1	42	55	421	138	3.70
25-Sep-91	3450	BR13	264	4	23	68	496	221	3.72

Elements in mg/L, pH in units

However, the zinc levels in the transient seeps (e.g. BR13), closer to Confederation Lake, were also higher at this time than previously measured.

The chemistry of water sampled from piezometers M18 and M38 were monitored more regularly than the transient seepages. In Table 18, it can be seen that the chemistry of the ground water at these locations in 1991 had not deviated from previous years. Piezometer M18 was installed at a depth of 8.2 m, and piezometer M38 at 6.58 m. This suggested that the water sampled from piezometers may not reflect the overall ground water characteristics of the mine site. It was decided that remedial actions for the mine site needed to be addressed immediately.

Table 18: Monitoring Data for Piezometers M18 and M38, 1986-1992 (mg/L)

PIEZOMETER M - 18								
Elemen	6/11/8	2/4/86	4/12/8	3/25/92	7/14/9	8/13/9	8/13/9	10/16/9
Al	0.58	1.2	1	<1	<1	<0.02	<0.02	<0.025
Ca	372	539	276	257	240	238	278	532
Fe	88	28	54	<1	<1	<0.00	<0.00	41.2
Mg	56	74	48	38	36.3	35.4	39.4	72.5
Na	18	22	15	10	9.58	9.14	10.1	17.7
S	327	390	347	214	215	202	227	325*
Zn	7.4	4.8	19	10	12.3	9.21	8.91	6.16
						pre bail	after bail	

* - determined by Boojum

PIEZOMETER M - 38										
Elemen	6/11/86	2/4/86	6/1/87	4/12/8	10/14/8	3/25/9	7/14/9	8/14/9	8/14/92	10/16/9
Al	0.58	0.9	0.2	0.4	0.01	<1	<1	<0.03	<0.03	<0.03
Ca	134	191	154	144	105	128	119	118	117	107
Fe	6.3	14.5	<0.01	2.2	0.1	2	<1	0.018	0.035	33.2
Mg	13	19	16	16	11	15	15.1	15.3	15.1	14.6
Na	5.7	6.3	5	6	4.1	5	4.86	4.82	4.62	4.72
S	125	173	172	156	89	86	80.5	77.4	75.6	59*
Zn	55	77	70	41	30	19	15.8	13.7	12.7	4.16
								pre bail	after bail	

* - determined by Boojum

In order to obtain a broader picture of the possible distribution of contaminants in ground water, a geophysical survey was carried out on the site in March 1992. Several maps were generated based on electromagnetic survey data at depths of 0 to 5 m, 10 m, and 20 m collected over a horizontal grid with 50 m spacing. These maps are included in Appendix B. The overall interpretation from the survey was that an area of high electrical conductivity was located 10 m below the top of Portal Raise, diminishing at a depth of 20 m. A likely contaminant source was the Backfill Raise, where electrical conductivities were high at the surface, and at 10 and 20 m below surface. It became clear from the survey that piezometers M38 and M18 were located in areas with low electrical conductivities, which explained the consistent water quality in these locations.

From the geophysical investigation, it was clear that during the summer of 1992, the exact location and origin of the seepages had to be determined. Remedial measures, which would curtail seepage flow to Confederation Lake, had to be identified.

Water samples were collected during 1992 for all surface water bodies (Map 6). In Table 19, it can be seen that all seepages on the mill site contained high zinc concentrations. The Portal Raise Seep sampled before and after heavy rain storms on July 14, 1992 and July 16, 1992 suggested that run-off water was contaminated. The two locations with the highest level of contaminants were Backfill Raise Cap (BRC) and the Warehouse Seepage, WHS. Water chemistries of the various Backfill Raise seepages in 1992 are shown in Table 20.

A conductivity, pH, and temperature survey of the water along the Confederation Lake shoreline near the mine site was carried out. Measurements were recorded from the surface, half way to the bottom, and at bottom of the water column. The sampling locations are given in Map 7 and the distribution of conductivities is plotted for the surface and bottom measurements in Map 8.

Table 19: Mine Site Seepages, 1992

Date	Ass.#	Location	Ca	Cu	Fe	Mg	S	Zn	pH
13-Jul-92	3868	PRS	126	1.50	<1	21	153	46	5.62
14-Jul-92	3873	BRC	476	1.85	19.5	129	831	642	5.61
14-Jul-92	3875	PRC	63	<1	<1	6	25	1	7.81
16-Jul-92	3877	PRS	94	19.60	3.7	16	175	122	3.51
14-Jul-92	3878	WHS	513	8.29	38.5	153	1070	919	3.24
13-Aug-92	4024	BRC	474	1.29	14.2	111	810	400	4.8
14-Aug-92	4037	PRC	86	0.04	0.25	10	41	3	6.28
14-Aug-92	4038	PRS	91	0.58	0.20	15	100	22	5.64
14-Aug-92	4039	WHS	483	7.46	74.2	132	976	492	3.55
16-Oct-92	4209	BRC	429	0.93	8.9	93	617*	500	5.55
16-Oct-92	4216	PRC	92	0.05	0.09	13	284*	7	6.62
16-Oct-92	4217	PRC	203	0.54	0.17	38	542*	114	6.17
16-Oct-92	4218	PRS	76	0.32	0.95	12	44*	23	5.99
16-Oct-92	4219	WHS	482	7.20	126	121	699*	880	3.58
18-Oct-92	4220	WHNP	107	0.42	26.4	19	1704*	118	3.36

* - determined by Boojum

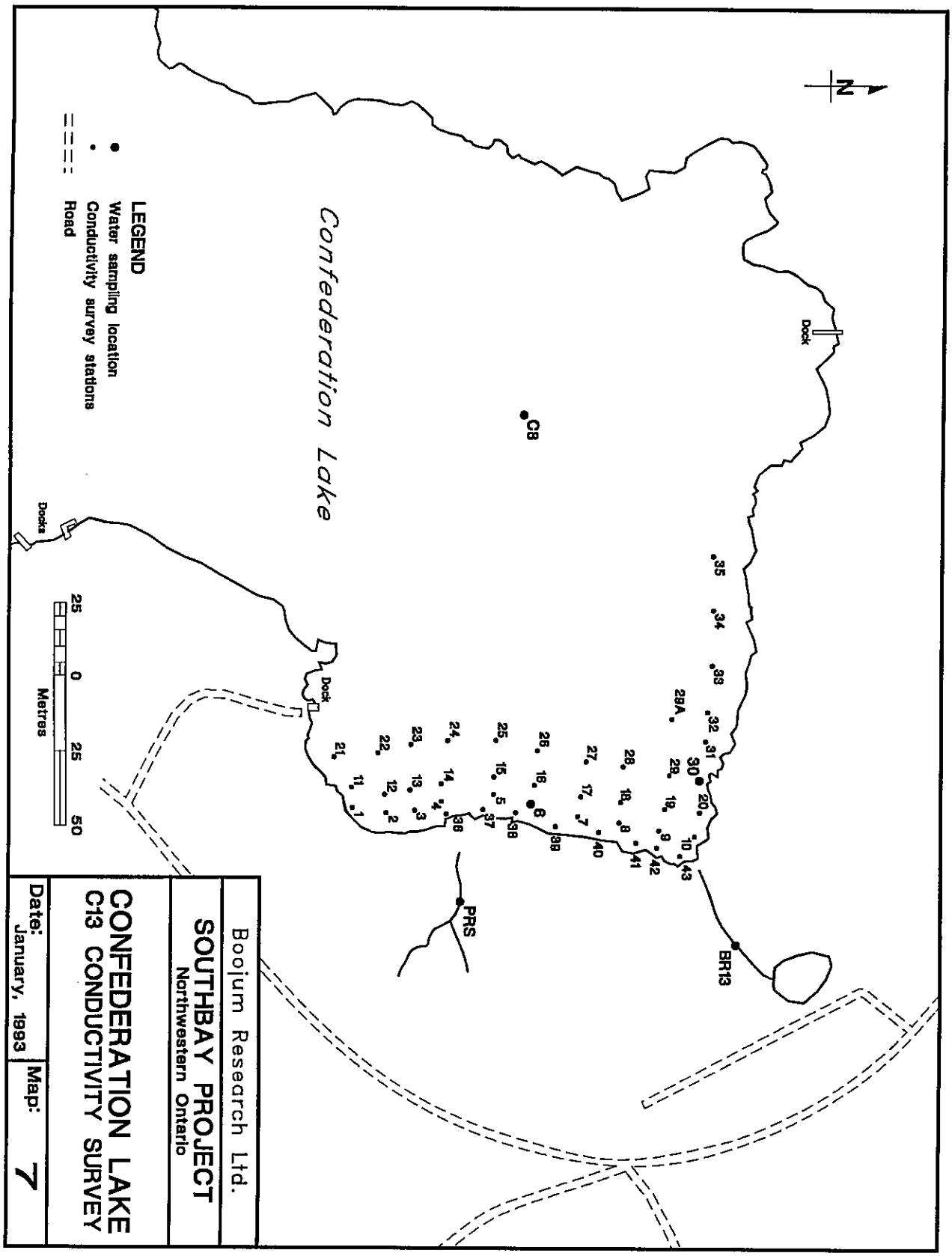
Elements in mg/L, pH in units

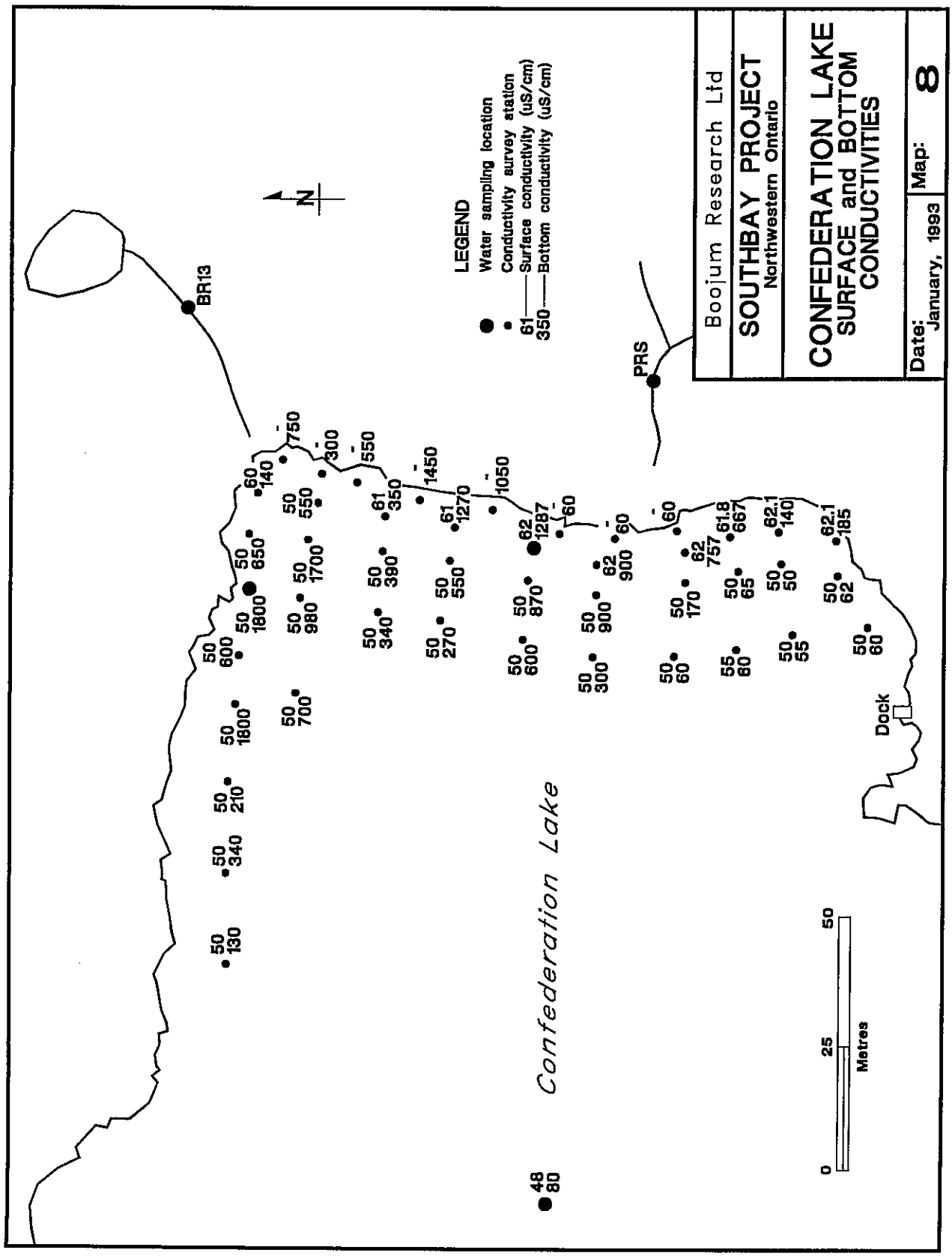
Table 20: Backfill Raise Seepages, 1992

Date	Ass.#	Location	Ca	Cu	Fe	Mg	S	Zn	pH
26-Mar-92	3675	BR13	302	<1	17.00	65	437	168	3.39
13-Jul-92	3867	BR13	221	<1	13.70	48	364	173	3.63
16-Jul-92	3876	BR13	118	<1	4.31	27	169	84	5.54
14-Aug-92	4019	BR13	240	1.02	20.60	54	396	163	3.61
14-Aug-92	4020	BR18	100	0.07	0.01	16	114	19	5.41
14-Aug-92	4021	BR13B	61	0.02	0.04	13	12	3	6.51
14-Aug-92	4022	BR13C	158	0.41	4.24	32	216	78	4.97
16-Oct-92	4210	BR13	207	0.68	5.10	42	660*	117	4.76
16-Oct-92	4211	BR18	215	0.30	5.80	32	804*	56	4.82

* - determined by Boojum

Elements in mg/L, pH in units


LEGEND
Water sampling location
Conductivity survey stations
Road
Confederation Lake
Dock
Docks
Dock
C8
PRS
BR13
25 0 25 50
Metres
Boojum Research Ltd.
SOUTHBAY PROJECT
Northwestern Ontario
CONFEDERATION LAKE
C13 CONDUCTIVITY SURVEY
Date:
January, 1993
Map:
7


Boojum Research Ltd
SOUTHBAY PROJECT
Northwestern Ontario
CONFEDERATION LAKE
SURFACE and BOTTOM
CONDUCTIVITIES
Date: January, 1993
Map: 8
LEGEND
Water sampling location
Conductivity survey station
61 — Surface conductivity (uS/cm)
350 — Bottom conductivity (uS/cm)
N
BR13
PRS
Dock
Confederation Lake
0
25
50
Metres

Given the elevated concentrations of metals in previously non-existent, or transient surface water bodies, on the mill site, a second site visit was carried out by Glen Mallory and Margarete Kalin on August 14th, 1992. Water samples were collected and sediments were obtained from the "hotspots" in Confederation Lake, at locations C13-30 and C13-6 (Map 8). Water quality results for these stations are shown in Table 21.

Table 21: Sediment Seepages in Confederation Lake, 1992

Date	Ass.#	Location		Ca	Cu	Fe	Mg	S	Zn	pH
25-Mar-92	3681	CS13	surface	19	<1	3.00	3	16	5	5.63
15-Jul-92	3886	C13-6	bottom	196	<1	4.25	32	237	63	5.73
15-Jul-92	3887	C13-30	bottom	129	<1	2.88	24	176	71	5.78
14-Aug-92	4015	C13-6	surface	8	<0.01	<0.01	1	2	0.28	6.90
14-Aug-92	4016	C13-6	bottom	62	<0.01	<0.01	11	64	18	6.04
14-Aug-92	4017	C13-30	surface	9	<0.01	<0.01	1	3	0.47	7.00
14-Aug-92	4018	C13-30	bottom	275	<0.01	20.6	46	358	142	5.80
17-Oct-92	4224	C13-6	surface	9	<0.01	0.06	1	60*	0.83	6.75
17-Oct-92	4225	C13-6	bottom	78	<0.01	0.03	12	1047*	36	6.25
17-Oct-92	4226	C13-30	surface	9	<0.01	0.02	1	84*	0.36	5.81
17-Oct-92	4227	C13-30	bottom	99	<0.01	3.54	19	252*	65	5.59
17-Oct-92	4228	C13-30	bottom	50	<0.01	0.20	9	948*	32	5.94

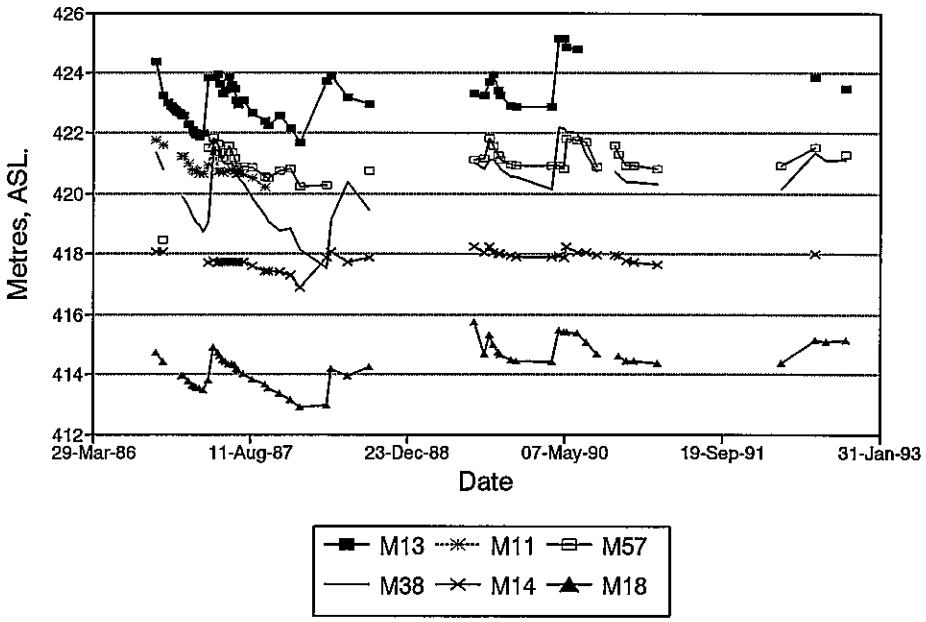
* - determined by Boojum

Elements in mg/L, pH in units

The locations C13-30 and C13-6 are of particular concern as the zinc concentrations in bottom samples collected during the July field trip were very high, containing 71 and 62 mg zinc L^{-1}, respectively. Clean surface samples collected in August indicated that the high concentrations of zinc were restricted to bottom samples. Surface water in both locations contained acceptable concentrations of zinc, 0.47 and 0.28 mg L^{-1}, respectively. The results of these water quality surveys suggested that seepages were emerging from beneath the sediment beyond the shore of Confederation Lake.

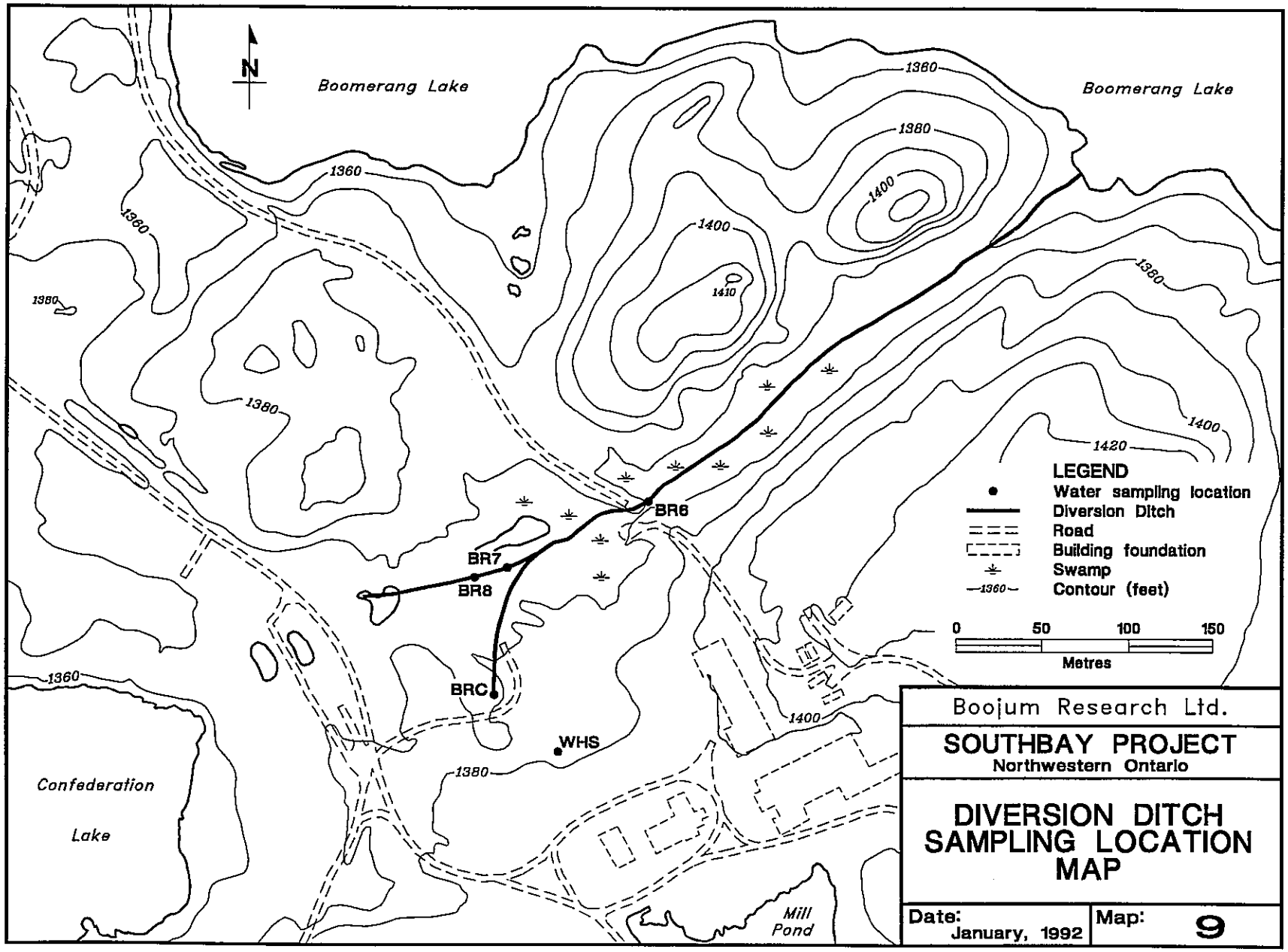
In Figure 21, the historic water levels are plotted for the mine site piezometers along with their hydraulic conductivities in 1986 for comparison to 1992 values. In this graph, it can be seen that in 1992, the water levels at some locations were above average, likely due to unusually high precipitation in this year.

Fig. 21: Mine Site - Piezometers
Water Levels, 1986 - 1993



A considerable amount of water chemistry data was collected during 1992. In light of the elevated zinc concentrations in the mine site seepages and in the Confederation Lake sediments close to shore, it was clear that the mine site required remedial action. Based on a preliminary analysis of the data, the decision to construct a larger diversion ditch was made. A significantly larger diversion ditch to Boomerang Lake was planned, and construction was completed by January 1993 (Map 9).

Field data were used to assess expected results following the construction. The details of the geochemical evaluation are given in Appendix C, and only brief excerpts are discussed below.


N
Boomerang Lake
Boomerang Lake
1360
1380
1400
1410
1420
BR6
BR7
BR8
BRC
WHS
Confederation
Lake
Mill
Pond
LEGEND
Water sampling location
Diversion Ditch
Road
Building foundation
Swamp
Contour (feet)
0
50
100
150
Metres
Boojum Research Ltd.
SOUTHBAY PROJECT
Northwestern Ontario
DIVERSION DITCH
SAMPLING LOCATION
MAP
Date:
January, 1992
Map:
9

7.2 Confederation Lake Survey

The conductivity survey data indicated imperfect vertical mixing, with the highest conductivities located near the bottom of the water column. The spatial variations in water conductivity and in pH indicated two separate areas of higher conductivity water with slightly lower pH, one northwest of the Portal Raise Seep, and the other southwest of Backfill Raise seep, BR13. This water with higher conductivity and slightly lower pH was found approximately 25 m from the shore. These results suggest that contaminated water was discharging into the sediments from beneath the lake. The spatial variation in conductivity, pH, and [Zn] suggested that the ground water flow of contaminated water discharged at the BR13 and Portal Raise Seep was bypassing piezometer M18 and the Portal Raise Cap.

The composition of the 1992 water samples collected from the seepages (and from piezometer M14) differed from the composition of water samples from piezometers M11, M18, and M38, and from BR13B and PRC. In the seepage waters, the concentrations of $Ca < SO_4$ and $Mg < Zn$; the piezometer waters, and the samples from PRC and B13B all showed $Ca > SO_4$ and $Mg > Zn$. As the origin of water collecting in piezometers is the lower part of the overburden and bedrock, this suggested that ground water contaminated with metals is moving through the overburden near the surface. Therefore, the proposed expansion of the diversion ditch would likely intercept this near surface flow.

7.3 Water Level Elevations

Water level elevations determined in the mine/mill area during 1992 indicated that water level decreased from M13 to M57; that water levels in the former M11, the Mill Pond, and M38 were relatively similar; that from there water levels decreased progressively to Warehouse Seep to Backfill Raise Pond to M18 to BRC/PRC to BR13 and Portal

Raise Seep, and finally, to Confederation Lake and the subaqueous seeps. In M14, in the Mill Pond run-off area, the water level was slightly lower than that of the Warehouse Seep.

The water level measurements made during 1992 in ponds and seepages suggested that the water levels decreased from Mill Pond to Warehouse Seep to Backfill Raise Pond to BRC/PRC to PRS. Water levels below the Backfill Raise Cap and below the Portal Raise Cap were virtually the same; they were likely to represent the water level in the mine.

Distances from the tailings spill site and from Mill Pond to Confederation Lake are about 260 m; distances from those points to Boomerang Lake are about 335 m and about 450 m, respectively. This means that, where bedrock does not obstruct flow, subsurface water would preferentially move towards Confederation Lake, due to a stronger gradient.

7.4 Variations in Chemical Composition with Time

Variations in the concentrations of S, Fe, Mn, Zn, Ca, and Cu (if present) were found in samples collected from piezometers M14, M18, M38, and M57 in the mine/mill area in the period from November 1986 to August 1992. With the exception of the [Mn] in M14, and possibly the [Fe] in M57, the other metal concentrations and sulphur showed a small long-term decrease. Compared to the other piezometers, the water in M14 was high in both zinc and copper.

The samples from the Warehouse Seep and Backfill Raise Cap showed minor dilution (decrease in S and Ca), and significant depression of the metal concentrations, which may be related to an increase in pH. Dilution was also noted for samples in Mill Pond between 24 March and 13 July (1992), and between 13 July and 18 July (1992). A

recovery in concentrations was noted between 18 July and 14 August (1992). Both the initial decrease and the subsequent increase were largest for [Fe].

The samples from the BR13 Seep showed dilution between 13 July and 16 July (1992), followed by a recovery between 16 July and 14 August (1992). Again, the effects were largest for [Fe].

The samples from the C13-30 Seep showed the effects of dilution from 24 March to 15 July (1992), followed by a recovery between 15 July and 14 August (1992). Again, [Fe] showed the largest effects.

The samples from the Portal Raise Seep showed an increase in concentrations (except [Ca]), between 13 July and 16 July (1992), followed by decreases in concentration between 16 July and 14 August (1992). Fe concentrations showed the largest effects.

The samples from the Portal Raise Cap showed increases in concentration between 14 July and 14 August (1992). Iron concentrations again showed the largest effect.

7.5 Geochemical Calculations

Degrees of Saturation (from WATEQ4F): In order to determine which minerals were likely to be dissolved by, or precipitated from, any of the selected water samples, the speciation program WATEQ4F (version 2.0, U.S.Geological Survey Open-File Report 91-183) was used to calculate saturation indices (SI values) for any minerals containing a combination of the elements determined during chemical analysis of the water samples. This information enabled the selection of the most likely dissolved and precipitated minerals to be used in the program NETPATH (version 1.5, U.S.Geological Survey Water-Resources Investigation Report 91-4078), as described in the next section of this report.

It was assumed that pyrite, chalcopyrite, and sphalerite were the minerals most likely to be dissolved by waters in the mine/mill area. The interpretation of the output is as follows: a positive SI value for a particular water, with respect to a particular mineral, means (1) that the water is supersaturated with respect to that mineral; **(2)** that the water is not likely to dissolve more of that mineral (if available); and (3) that the mineral may be precipitated from the water. If supersaturation is shown, with respect to more than one mineral containing the same elements, then the mineral showing the highest SI value is most likely to precipitate.

It should also be pointed out that, due to the lack of data on the concentrations of carbon species, chloride, nitrate and phosphate, all carbonate, chloride, nitrate and phosphate minerals had to be omitted from consideration.

The main observations from the WATEQ4F results are:

1. All samples containing Ba showed supersaturation with respect to barite.
2. All samples containing Cu showed supersaturation with respect to cuprous ferrite.
3. All samples containing Fe showed supersaturation with respect to goethite and hematite.
4. All samples containing Al showed supersaturation with respect to annite; some also showed supersaturation with respect to boehmite and gibbsite; the samples from BRC, PRS, and the gravel-pit pond also showed supersaturation with respect to one or more clay minerals.
5. All samples except that from the gravel-pit pond ([Si]=0.34 mg/L) showed supersaturation with respect to quartz.
6. All samples except those from Warehouse Seep, Mill Pond, and BR13, showed supersaturation with respect to $ZnSiO_3$. The July and August samples from Warehouse Seep, Mill Pond, and BR13 were under-saturated with respect to this mineral.

The use of laboratory measurements of Eh may, of course, have distorted the extent of goethitelhematite supersaturation, whereas the use of laboratory measurements of pH may have distorted the extent of supersaturation with respect to pH-sensitive minerals, including goethite, hematite, boehmite, and gibbsite.

Dissolution. Precipitation, Mixing, and Dilution (using NETPATH): A second geochemical model NETPATH was used to determine the composition of seepages. In contrast to the first model, which predicts the likely metals which are removed due to geochemical precipitation, it determines the proportions in which clean and contaminated water are mixed.

For some of the sample sources, precipitation (rain or snowmelt), or uncontaminated ground water, was assumed to be the original input ("Initial Source"), and NETPATH was used to determine how much of which minerals had to be dissolved (or precipitated) to derive the final water ("Final Source"), as sampled. For some of the other sources, a mixture of contaminated and uncontaminated waters ("Initial Source 1" and "Initial Source 2") was assumed as input, and NETPATH was used to determine the probable mixing ratio, as well as possible mineral dissolution and precipitation. Finally, for some of the sample sources two samples taken before and after dilution by rain or snowmelt ("Initial Source" and "Final Source") were used in NETPATH to determine the dilution ratio.

The water level relationships suggested that piezometers M57, M38, and the destroyed piezometer close to the shaft (M11), Warehouse Seep and Mill Pond as well as probably Backfill Raise Pond and M18 received their heavy-metal contamination from near-surface sulphide sources on the mine/mill site; that Backfill Raise Cap and Portal Raise Cap both contain mine water; and that BR13, C13-30, and Portal Raise Seep discharge water with progressively smaller fractions of heavy-metal contaminated water.

The NETPATH model output indicated that the Warehouse Seep water could be derived from either precipitation or uncontaminated ground water through dissolution of oxygen, sphalerite, pyrite, minor chalcopyrite, and some feldspar, and precipitation of goethite (or hematite), silica, and gibbsite.

Backfill Raise Cap water sampled July 14, 1992, can be derived from either precipitation or uncontaminated ground water through dissolution of somewhat smaller amounts of oxygen, sphalerite, pyrite, a trace of chalcopyrite, and some feldspar, and precipitation of goethite, silica, and gibbsite.

The Portal Raise Cap water of 14 August (1992) can be derived from a mixture of some 4 % Warehouse Seep water and 96 % uncontaminated ground water or from a mixture of about 5 % Backfill Raise Cap water with 95 % uncontaminated ground water, accompanied by dissolution of minor amounts of oxygen and feldspar, and precipitation of minor amounts of zinkite, goethite, and copper sulphate (or, more likely, carbonate). The decreases in Ca/S and Ca/Zn ratios, and increases in sulphur and heavy-metal concentrations between 14 July and 14 August (1992) indicated that the percentage of contaminated water in Portal Raise Cap water was increasing.

The Portal Raise Seep water sampled 13 July, 1992, can be derived from a mixture of some 14 % Warehouse Seep water and 86 % uncontaminated ground water, accompanied by dissolution of minor amounts of oxygen, feldspar, and chalcopyrite, and precipitation of zinkite, and a minor amount of goethite. Between July 13 and August 14, 1992, the Portal Raise Seep water was likely diluted by a factor of about 1.5, accompanied by dissolution of trace amounts of oxygen and pyrite, and precipitation of some zinkite and trace amounts of copper sulphate and MnOOH. The decrease in the percentage of Warehouse Seep water between July 13 and August 14, 1992, is indicated by decreases in metal concentrations and a change in the Ca/S ratio. The peak in sulphur and metal concentrations on July 16, 1992, may well reflect the discharge of a slug of contaminated water, pushed by infiltrating rain water.

Mill Pond water can be derived from precipitation through dissolution of oxygen, sphalerite, pyrite, and some chalcopyrite and feldspar, and precipitation of goethite, and some silica. Between July 13 and 18, 1992, Mill Pond water was likely diluted by a factor of about 1.3, accompanied by dissolution of a trace amount of oxygen, and precipitation of some zinkite and trace amounts of copper sulphate and MnOOH. Similarly, it is likely that the sample of August 14, 1992 was a mixture of about 90 % of Mill Pond water of July 13, 1992 and 10 % precipitation, accompanied by dissolution of a trace amount of silica, and precipitation of zinkite, some gibbsite, and a trace amount of copper sulphate or possibly carbonate.

BR13 water can be derived from a mixture of some 43 % Backfill Raise Cap water and 57 % uncontaminated ground water, accompanied by dissolution of minor amounts of oxygen, pyrite, and feldspar, and precipitation of zinkite, and minor amounts of MnOOH and cuprous-ferrite. Between July 13 and 16, 1992, Portal Raise Seep water was likely diluted by a factor of about 2.2, accompanied by dissolution of trace amounts of oxygen and sphalerite, and precipitation of trace amounts of goethite and MnOOH.

The C13-30 water can be derived from a mixture of some 41 % Backfill Raise Cap water and 59 % uncontaminated ground water, accompanied by dissolution of minor amounts of oxygen and pyrite, and precipitation of zinkite, and minor amounts of MnOOH, cuprous-ferrite, and silica. Between July 15 and August 14, 1992, the Portal Raise Seep water recovered from a likely dilution by a factor of about 2.0, which had been accompanied by dissolution of trace amounts of oxygen, sphalerite, and MnOOH, and precipitation of a trace amount of goethite.

The results of the geochemical modelling support the earlier conclusions, that the higher water levels in 1992 flushed out contamination, which would normally have remained in the mine site overburden, or have been released slowly through the sediments in Confederation lake along the shore.

The diversion ditch which has been completed in January 1993 should curtail the seepages to Confederation Lake.

Perforation of the Backfill Raise at the level of the new drainage ditch will limit the maximum possible water level in the mine, and this will, in turn, reduce the potential for discharge of highly contaminated water from the mine, through the Portal area, to Confederation Lake.

8. DISCUSSION AND CONCLUSIONS

At the onset of the project in 1986, there was a considerable amount of uncertainty associated with the Ecological Engineering approach. Although conceptually a self-sustaining low maintenance, decommissioning approach appeared feasible for the South Bay site, many components of the technology were undeveloped.

The key process which has been implemented at the mine site, Boomerang Lake, and Decant Pond is biological polishing. It can be concluded that annual contaminant loadings can be addressed by periphyton growth and ARUM.

Estimates of the effectiveness of the polishing system vary widely, depending on the type of growth rates used (exponential or linear) and on the uptake/ adsorption/ precipitation rates. A combination of field and laboratory experiments were used to derive the relevant parameters to quantify the metal removal process which is mediated by periphyton. Both experimental approaches highlight several factors which contribute to the performance. For example, light and fertilizer additions increased growth in the laboratory, but the light intensity in the laboratory can not be directly related to the actual light intensity the field populations are experiencing. The growth rates increased both in the laboratory and in the field through additions of fertilizer. However, no significant amounts of fertilizer have been added to any of the water bodies to date.

It has to be concluded that the system performance will likely increase at the time that all scale-up measures are taken. The current estimates of the removal capacity are based on data collected from periphyton populations under severely stressing environmental conditions.

A technical challenge, in the development of Ecological Engineering as a decommissioning strategy, was to find an ecosystem-compatible approach to remove the accumulated contaminants within the waste management area. Natural phosphate

rock was found to fill such a requirement. Phosphate has many ecosystem-friendly advantages. It can raise pH, precipitate metals, provide fertilizer for periphyton, and enhance sediment processes which will assist contaminant retention by sediments.

In conclusion, the original concept of Ecological Engineering, that a new ecosystem can be developed within the waste management area, has been substantiated. This ecosystem has the capacity to address annual contaminant loadings. In 1993, a scale up of the system will be possible. This time frame is within the projected decommissioning requirements.

9. RECOMMENDATIONS

There are three aspects of the waste management area which need to be addressed.

Boomerang Lake

In Boomerang Lake, the residual acidity which has been accumulating since 1981 must be dealt with. It is proposed that this accumulation be removed with phosphate rock. The experimental application of phosphate rock to a fraction of the lake was successful. The interaction between sediments and phosphate was found to be important.

In order to achieve this objective, the following tasks have to be completed:

1. Address the Redox conditions in Boomerang Lake sediments.
2. Resample the sediments from the locations where phosphate rock was applied.
3. Carry out ***in situ*** (field) additions of phosphate rock to different sediment types, varying by organic content.
4. Determine the microbial activity in the sediments.
5. Develop a phosphate rock application method.

Mine/Mill Site

The tasks for the new Backfill Raise diversion ditch are as follows:

1. During spring run-off, the contaminant loadings should be evaluated.
2. Flows should be quantified during the summer months, as the magnitude of these flows will determine the effect on Boomerang Lake.
3. The diversion ditch should be stabilized. Stabilization requirements of the ditch banks needs to be determined after the hydrological conditions of

the diversion ditch are assessed. It is likely that a combination of semi-aquatic and terrestrial vegetation should be promoted. Establishment of semi-aquatic vegetation would promote biological polishing.

4. The effect of phosphate rock, which was applied to Mill Pond, has to be evaluated.

Decant Pond

The tasks which should be completed at Decant Pond include the following:

1. The development of ARUM along the tailings beach should be confirmed through water and sediment sampling.
2. The performance of the coarse phosphate rock, placed on the perched water table on the tailings should be quantified.

10. APPENDICES

APPENDIX A LIST OF REFERENCES, PAPERS AND REPORTS

APPENDIX B ELECTROMAGNETIC SURVEYS AT SOUTH BAY, GEOMAR 1992

APPENDIX C SEEPAGES OF THE SOUTH BAY MINE/MILL SITE., by R.O. VAN EVERDINGEN, NOVEMBER 1992.

APPENDIX D BOOJUM QA/QC INFORMATION

APPENDIX E WATER AND SEDIMENT ICP DATA

APPENDIX A LIST OF REFERENCES, PAPERS AND REPORTS

1992. Ten Hulscher T.E.M., G.A.J. Mol, F. Luers. Release of metals from polluted sediments in a shallow lake: quantifying resuspension. Hydrobiologia 235-236: 97-105.

1992. Kalin, M. R.O. van Everdingen, R.G.L. McCready. "Ecological Engineering interpretation of hydrogeochemical observations in a sulphide tailings Deposit." CIM Bulletin 85: 64-67.

1992. Kalin, M., W.N. Wheeler. "Periphyton Growth and Zinc Sequestration". Proceedings 1992 BIOMINET Annual Meeting, Edmonton, Alta, August 1992 (in press).

1992. Kalin, M., W.N. Wheeler. "A study of algae-precipitate interactions." Final Report to CANMET, DSS File #034SQ.23440-1-9011, 58 p.

1991. Kalin, M., "Ecological engineering applied to base metal mining wastes for decommissioning." Proceedings 1990 BIOMINET Annual Meeting, 1991 (in press).

1991. Kalin, M., W.N. Wheeler, R.O. van Everdingen. " Periphyton communities as biological polishing agents in mine waste waters and the precipitation process in tailings." Final Report to CANMET, DSS File 028SQ.23440-0-9182, 54 p. + appdx.

1990. Kalin, M., "Ecological engineering applied to base metal mining wastes." Proceedings of the Canadian Land Reclamation Association (CLRA), 15th Annual Meeting, Acidity and Alkalinity in Terrestrial and Aquatic Reclamation, 1990, pp. 105-112.

1990. Kalin, M., "Ecological engineering applied to base metal mining wastes." In, Acid Mine Drainage - Designing for Closure (J.W. Gadsby, J.A. Malick, and S.L. Daly, editors), p.407-414. Papers presented at the 1990 GACIMAC Joint Annual Meeting, Vancouver.

1989. Kalin, M., "Ecological engineering and biological polishing: Methods to economize waste management in hard rock mining," in Ecoloclical Enaineerina: An introduction to Ecotechnoloclv, W.J. Mitsch and S.E. Jorgensen (Eds.), John Wiley & Sons, Inc., Toronto, pp. 443-461.

1989. Kalin, M., "Ecological engineering applied to base metal and uranium mining wastes."Proceedings of the 1989 Biohydrometallurgy Conference, Jackson Hole, Wyoming, August 13-18, 1989, pp. 363-368.

1989. Kalin, M., R.O. van Everdingen and G. Mallory, "Ecological engineering measures developed for acid-generating waste - The close-out of a decant pond." Proceedings of the International Symposium on Tailings and Effluent Management, Halifax, Nova Scotia, August 20-24, 1989, pp. 195-204.

1989. Kalin, M., M. Olaveson and B. McIntyre, "Phytoplankton and Periphyton Communities in a Shield Lake Receiving Acid Mine Drainage in NW Ontario." Proceedings of the Fifteenth Annual Aquatic Toxicity Workshop: November 28-30, 1988, Ed. R. Van Coillie et al., 1989. pp. 166-187.

1989. Kalin, M., M.P. Smith and R.O. van Everdingen, "Ecological engineering measures developed for acid generating waste from a copper/zinc concentrator in Northern Ontario." Proceedings of the Conference "Reclamation, A Global Perspective," Calgary, Alberta, August 27-31, 1989, pp. 661-672.

1988. Kalin, M., "Ecological engineering and biological polishing methods to economize waste management." Proceedings of the 20th Annual Meeting of the Canadian Mineral Processors Ontario, January 19-21, 1988, pp. 302-318.

1988. Kalin, M., "Ecological engineering and biological polishing: Its application in close-out of acid generating waste management areas." Proceedings of the 1988 Mine Drainage and Surface Mine Reclamation Conference, Sponsored by the ASSMR, Pittsburgh, Pennsylvania, April 19-21, 1988, p. 399.

1988. Kalin, M. and R.O. van Everdingen, "Ecological engineering: Biological and geochemical aspects, Phase I experiments." in Environmental Management of Solid Waste, W. Salomons and U. Forstner (Eds.), Springer-Verlag, New York, pp. 114-128.

1988. van Everdingen, R.O., H.R. Krouse. "Interpretation of isotopic compositions of dissolved sulphates in acid mine drainage". Paper presented at the annual meeting of the American Society for Surface Mining and Reclamation, April 17-22, 1988, Pittsburgh, PA.

APPENDIX B ELECTROMAGNETIC SURVEYS AT SOUTH BAY. GEOMAR 1992

EM SURVEY
SOUTH BAY RECLAMATION PROJECT
SOUTH BAY, ONTARIO

PREPARED FOR
BOOJUM **RESEARCH LIMITED**

PREPARED BY
GEOMAR GEOPHYSICS LTD

MISSISSAUGA
ONTARIO

APRIL, **1992**

1.0 INTRODUCTION

A geophysical survey was carried out in March, 1992 in the vicinity of Town of South Bay, Ontario. The purpose of the survey was to detect the presence of contaminants and abandoned structures at the South Bay mine site. The work was authorized by M. Kalin of Boojum Research Limited.

2.0 SURVEY DESCRIPTION

2.1 General

In its natural (uncontaminated) state, ground water acts as a relatively poor electrical conductor. However, the presence of inorganic contaminants in the ground water *can* increase the ground water electrical conductivity and thus the electrical conductivity of the saturated soil.

Generally, ground conductivity depends principally on (McNeill, 1987):

- soil structure (coarser structure and smaller porosity producing lower conductivity)
- clay content (increasing clay fraction) producing higher Conductivity
- soil moisture content (increasing moisture producing higher conductivity)
- conductivity of included pore water.

The conductivity of a water (electrolyte) is proportional both to the total number of ions in the solution and their mobility. The mobility is different for different ions since it depends on their diameter. Values for some common ions are given in table 1.

Table 1. Mobility of common ions at 25°C
(after Keller and Frischknecht, 1966)

Ion	Mobility (m^2/sec V)
H^+	36.2 x 10''
OH^-	20.5 x 10^{-8}
SO_4^-	8.3x 10''
Na^+	5.2 x 10''
Cl^-	7.9 x 10''
K^+	7.6 x 10''
NO_3^-	7.4 x 10''
Li^+	4.0 x 10''
HCO_3^-	4.6 x 10''

It has been shown that for average unconsolidated soil, an increase of approximately 25 ppm of total dissolved solids (TDS) of sodium chloride (NaCl) to soil water will increase the saturated bulk soil conductivity by 1 mS/m (McNeill, 1987).

In order to best delineate the extent of contamination, a method that can resolve relative changes in the subsoil conductivity caused by increases/decreases in the concentration of contaminant in terms of total dissolved solids can be employed. For this reason a Fixed Frequency Electromagnetic (EM) Profiling technique were employed for this survey. The basic principles of the technique are briefly outlined below.

2.2 Fixed Frequency EM **Profiling**

In the EM method, eddy current flow is induced in the ground by a time varying magnetic field of a vertical or horizontal magnetic transmitter dipole operating at a fixed frequency. This

eddy current flow induces a secondary magnetic field which, together with the primary field, is sensed by a similar receiver dipole. The ratio of the primary field and secondary fields is related to the conductivity of the subsurface.

The instrument configuration, frequency and coil separation, are selected so that operation can be described by the low induction number approximation (range in which the true conductivity is linearly proportional to the apparent conductivity indicated by the instrument, McNeill, 1980) over a relatively large range of terrain conductivities. In this sense, each induced eddy current loop is independent of the others and the measured signal can be thought of as a linear superposition of the responses of strata within the exploration range of the array used. The effective exploration depth of the EM equipment can be varied by changing one or more of loop spacing, loop orientation (vertical or horizontal), or height above the ground. Figure 3.1 shows relative responses for vertical and horizontal dipoles (where z is the depth normalized by intercoil spacing s).

Frequency domain EM profiling can also be used for down-hole geophysical investigations. In this case the tool is lowered down a drill hole. Then, with properly selected parameters of the arrangement (such as the tool length, frequency, etc.), the measurements will be referred to the conductivity of the subsurface in the vicinity of the plastic-cased (or open) borehole. The instrument is essentially insensitive to borehole fluid conductivity. This technique is used in the case when the detailed monitoring of the vertical distribution of the formation conductivity is required.

2.3 Instrumentation

The Fixed Frequency EM measurements were carried out using Geonics EM31-DL and EM34-3 terrain conductivity meters.

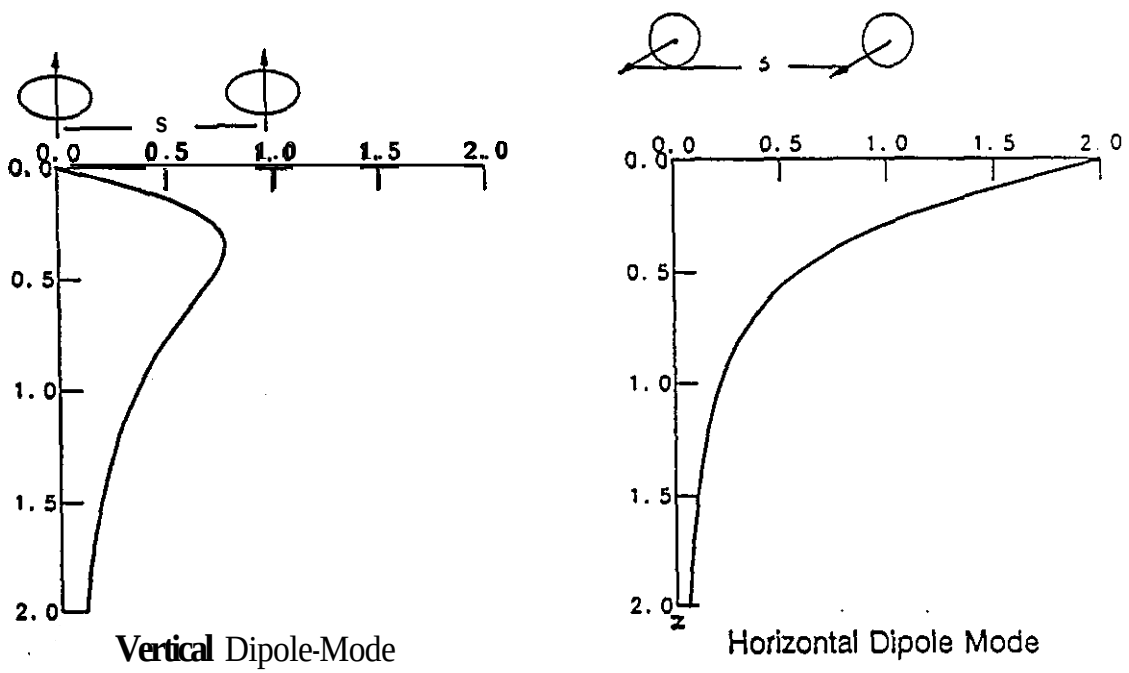


Figure **3.1** Relative responses for vertical and horizontal dipoles.

The measurements with **EM31-DL** were taken with vertically oriented magnetic dipoles at hip level. The instrument in *this* configuration has a depth of penetration up to *6* m. The distance between **the** measurement points along the survey lines varied from **1** to **2** m.

The approximate exploration depths for **EM34-3** instrument at various intercoil spacing are given in Table **2.** The relative contribution from material at different depths to the conductivity indicated by the instrument meter is discussed in detail in literature (McNeill, **1980).**

Table 2. Approximate Exploration Depths for EM34-3 at various intercoil spacings.

Intercoil Spacing (meters)	'Exploration Depth (meters)	
	Horizontal Dipoles	Vertical Dipoles
10	7.5	15
20	**15**	**30**

The measurements with EM34-3 were taken at a distance of 10 m along survey lines. The intercoil spacing for the horizontal dipole mode was 10 and 20 m, while for the vertical mode it was 20 m.

It should be understood that there are other factors, besides the presence of contaminants, which can affect conductivity of the subsurface. The major **ones are** lithology and water content. Factors affecting the soil conductivity were discussed above, and they are described in detail in literature (McNeill 1980, and 1987). Those factors were taken into account in the description of the survey results.

3.0 LOGISTICS

The survey was carried out by a two man crew. Both the crew and equipment were mobilized from Mississauga to Town of Ear Falls by air. Local commercial facilities were used to accommodate the crew. The crew travelled daily to the mine site by truck.

Three grids were surveyed in six days. Out of those, two days were spent for laying out the grids, one day for EM31 measurements, and three days for EM34 measurements. The presence of strong atmospheric noise and the weather conditions precluded the acquisition of EM34 data for all grids.

4.0 RESULTS

The results of the survey are present in the form of coloured maps for each reading and each grid. A number of areas of anomalous conductivity can be clearly seen on each grid. The analysis of readings to different exploration depth shows that the anomalous objects occur as a rule at shallow depths. The linear anomaly detected near Confederation Lake at the mine site presents an exception. The amplitude of the anomaly is the greatest in EM34 10H reading.

5.0. CONCLUSIONS AND RECOMMENDATIONS

A number of anomalies of increased conductivity were detected at all grids. The anomalies appear to be in agreement with available information regarding the distribution of contaminants and location of abandoned structures.

Regarding future studies, the following recommendations can be made:

Since many of the anomalies are produced by targets of small lateral extent, tighter survey grid can be strongly recommended. This would help to outline the extent of anomalies more accurately and clarify their nature.

The technique used is very efficient in mapping lateral variations in the subsurface conductivity, The use of a sounding technique can be recommended for delineating these variations in section view.

Many drill holes are available at the site. It will be beneficial to perform downhole geophysical measurements. This would allow for accurate determinations of lithology and ground water properties and provide valuable information for the analysis of surface data.

BIBLIOGRAPHY

1. G.V. Keller, F.C. Frischknecht (1966) "Electrical Methods in Geophysical Prospecting". Ch.1. Pergamon Press, N.Y.

2. J.D. McNeil (1980) "Electrical Conductivity of Soils and Rocks" . Geonics Limited, Technical Note TN-5, 22 p.

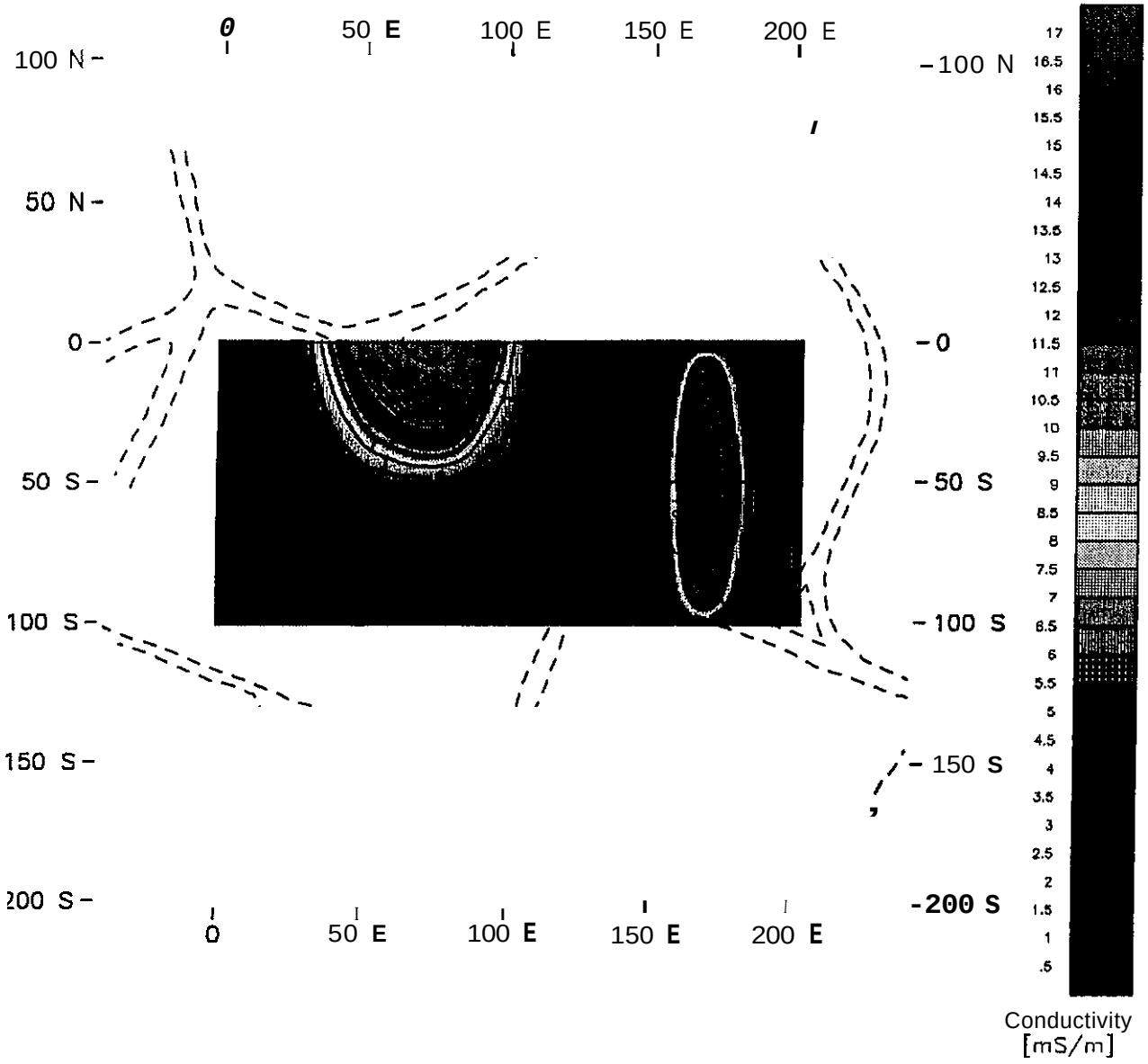
3. J.D. McNeil (1980) "Electromagnetic Terrain Conductivity Measurements at Low Induction Number". Geonics Limited, Technical Note TN-6, 15p.

4. J.D. McNeil (1987) "Advances in Electromagnetic Methods for Groundwater Studies". In: Proc. of Exploration '87, Ontario Geological Survey, Special Volume 3. 678 - 702.

Respectfully submitted
per
Geomar Geophysics Ltd.

J. Pawlowski, M.Sc.,
President

G. Rozenberg, M.Sc.



Scale 1:2400

25 0 25 50 75 100

(metres)

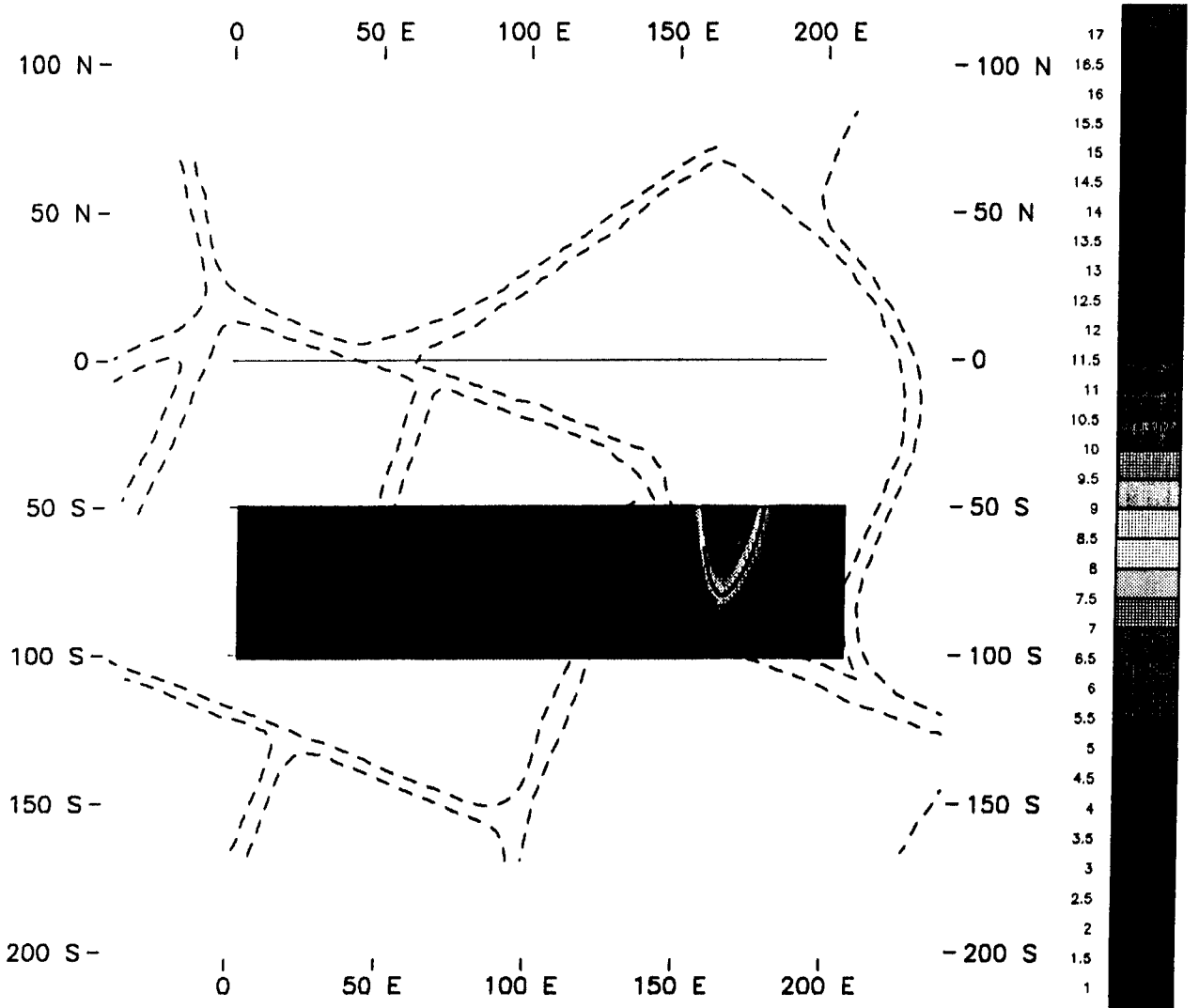
BOOJUM RESEARCH LIMITED

SOUTH BAY
DIVERSION DITCH
March, 1992

ELECTROMAGNETIC SURVEY
INSTRUMENT EM31–DL
VERTICAL DIPOLE MODE
Soil Conductivity in mS/m
—— – Survey Line

Geomar Geophysics Ltd.

Map 2–A



Conductivity [mS/m]

Scale 1:2400

25 0 25 50 75 100

(metres)

BOOJUM RESEARCH LIMITED

SOUTH BAY DIVERSION DITCH

March, 1992

ELECTROMAGNETIC SURVEY

INSTRUMENT EM34-3

HORIZONTAL DIPOLE MODE

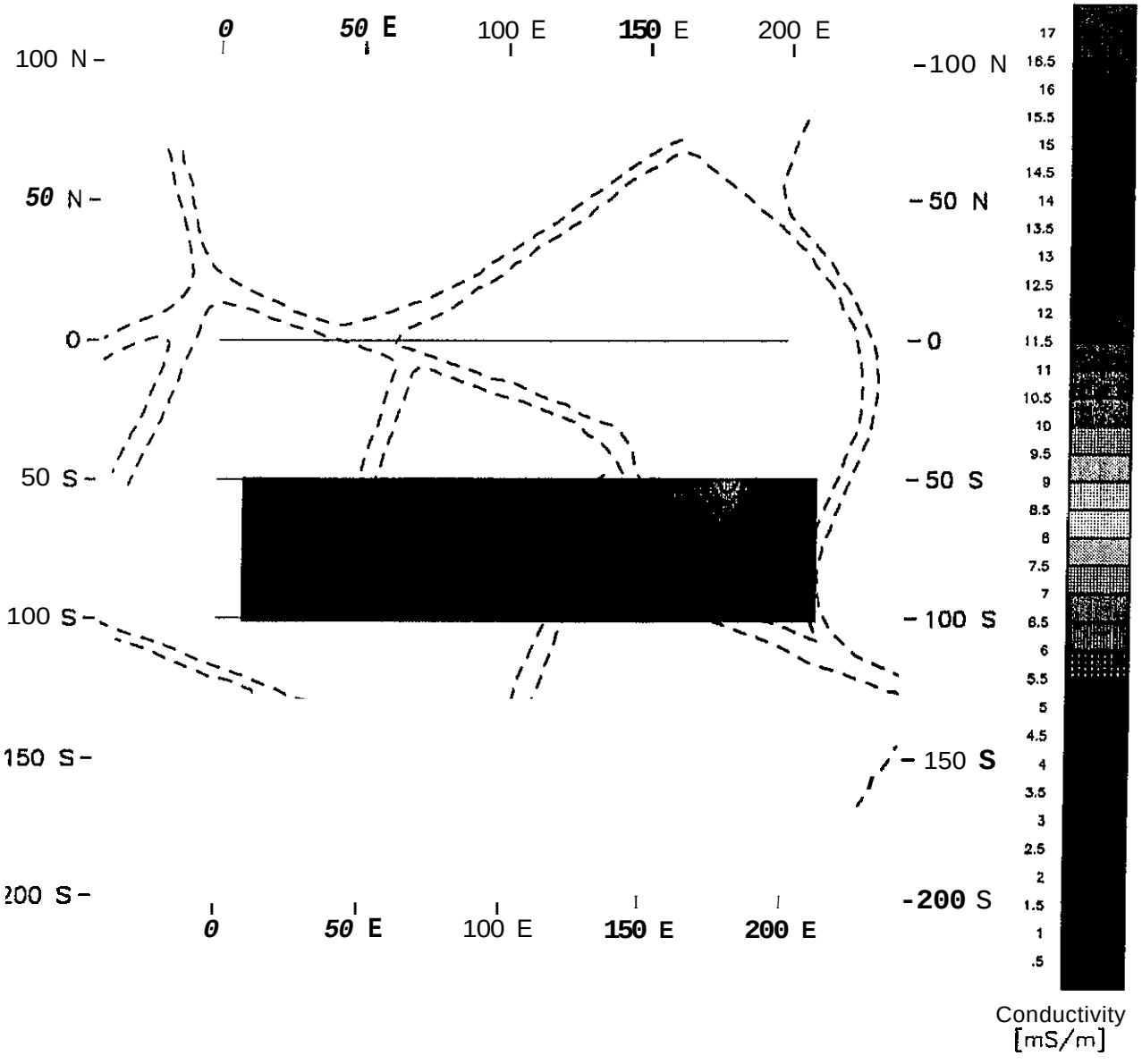
COIL SEPARATION 10 m

Soil Conductivity in mS/m

——— – Survey Line

Geomar Geophysics Ltd.

Map 2-B



Scale 1:2400

25 0 25 50 75 100

(metres)

BOOJUM RESEARCH LIMITED

SOUTH BAY
DIVERSION DITCH
March, 1992

ELECTROMAGNETIC SURVEY

INSTRUMENT EM34-3

HORIZONTAL DIPOLE MODE

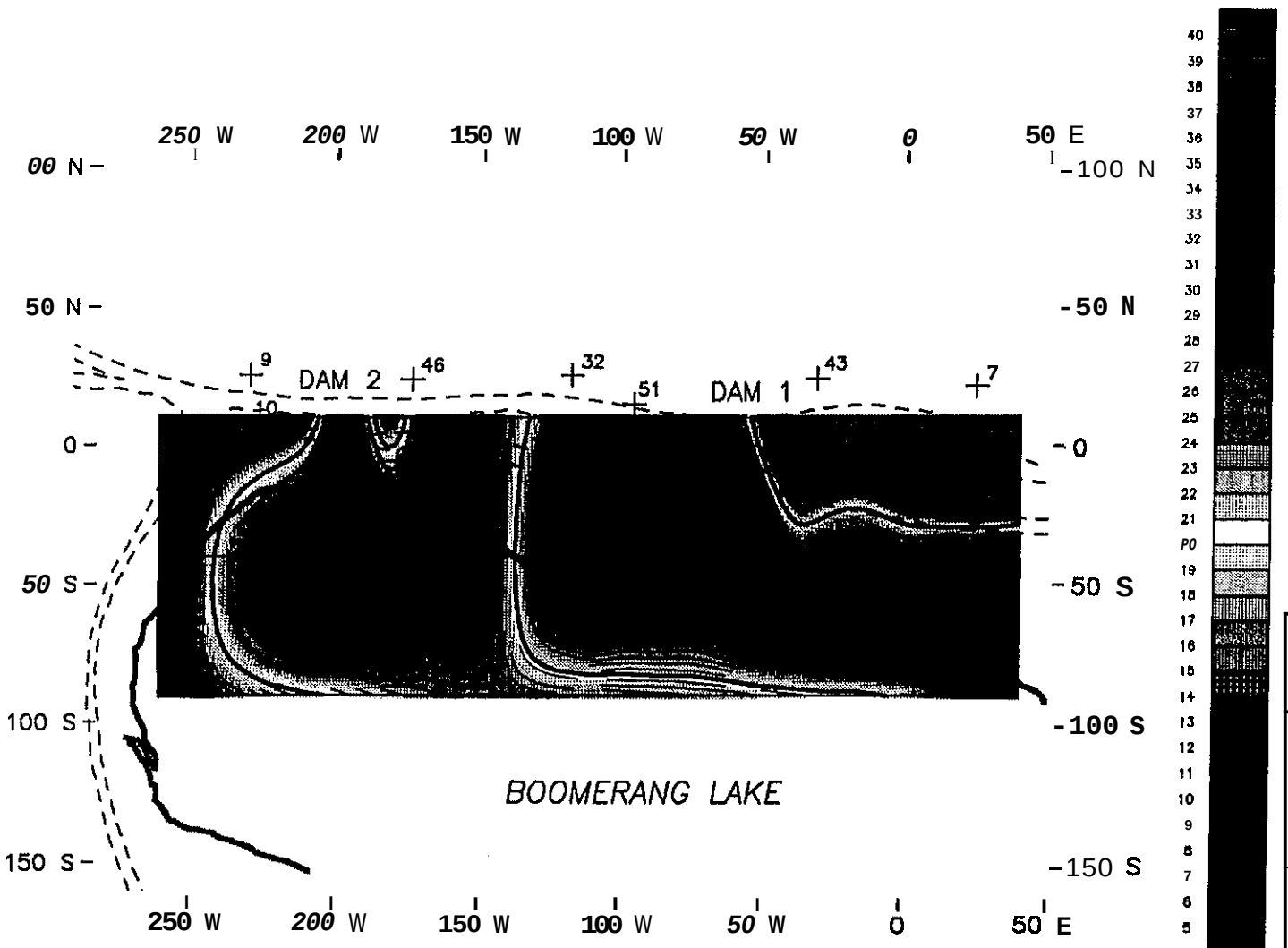
COIL SEPARATION 20 m

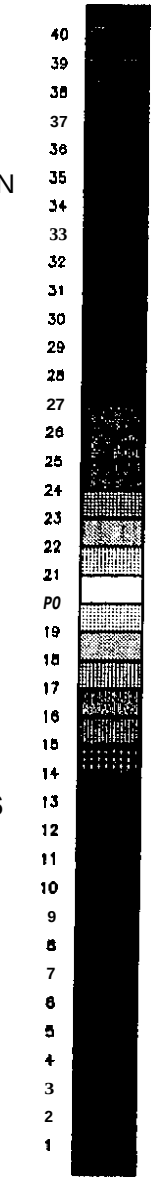
Soil Conductivity in mS/m

——— - Survey Line

Geomar Geophysics Ltd.

Map 2-C



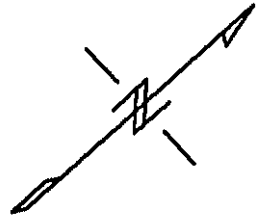


Conductivity [mS/m]

Scale 1:2400

25 0 25 50 75 100 125

(metres)



BOOJUM RESEARCH LIMITED

SOUTH BAY TAILINGS DAMS 1 & 2

March, 1992

ELECTROMAGNETIC SURVEY INSTRUMENT EM31-DL

VERTICAL DIPOLE MODE

Soil Conductivity in mS/m

—— – Survey Line

Geornar Geophysics Ltd.

Map 3-A

APPENDIX C SEEPAGES OF THE SOUTH BAY MINE/MILL SITE. By R.O. VAN EVERDINGEN, NOVEMBER 1992.

SEEPAGES OF THE SOUTH BAY

MINE/MILL SITE

BY: R. van EVERDINGEN

NOVEMBER 1992

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SEEPAGES OF THE SOUTH BAY MINE/MILL SITE

A. CONFEDERATION LAKE SURVEY

In mid-July 1992 the area of Confederation Lake along the shore of the South Bay mine/mill site was surveyed, and several water quality parameters were measured at a number of points. The results are listed in Table 1 and illustrated by Figures 1A-ID. The locations are shown in Figure 1A and water depths in Figure 1B. Results of the measurements of conductivity and pH are shown in Figures 1C and ID, respectively. The figures include the locations of, and measurements in, the Backfill Raise Pond (BRP), Piezometer M18, seepage pond BR13, the Portal Raise Cap (PRC), and the Portal Raise Seep (PRS), for comparison. (Note that the Easting and Northing scales on these figures are not the same).

The data in Table 1 indicate imperfect vertical mixing, with the highest conductivity being found near the bottom. The areal variations in water conductivity (Figure 1C) and in pH (Figure ID) indicate two separate areas of more highly conductive water with slightly lower pH, to the WNW from point PRS, and to the WSW from point BR13. The more conductive water with lower pH was found some (minor) distance out from the shore. These results suggest that contaminated water is discharging from the lake-bottom sediments, some distance from the shore.

Table 2 lists partial analyses (pH, Cu, Zn, Fe, S, Ca, and Mg) for water samples collected from various points in the mine/mill area at various times between November 1986 and August 1992. Zinc concentrations for samples collected in July 1992 are plotted in Figure 2A. The areal variation in conductivity and pH values (Figures 1C and ID), and in [Zn] values (Figure 2A) suggest that the more highly contaminated water discharged at points BR13 and the PRS seeps has bypassed Piezometer M18 and the Portal Raise Cap.

The composition of the 1992 samples from the seepages (and from Piezometer M14) differs from the composition of samples from piezometers M11, M18, and M38 (and from BR13B and PRC). In the seepage waters, $Ca<SO_4$ and Mg<Zn; the piezometer waters, and the samples from PRC and B13B all show $Ca>SO_4$ and Mg>Zn. As the piezometers sample the lower part of the overburden, and bedrock, this suggests that heavy-metal contamination is concentrated in the near-surface overburden.

The following may be sources for the heavy metals in the seepage:

a - tailings spill(s);

b - contaminated materials in the former Backfill Raise pond;

c - contaminated 'fill' on the minelmill site;

d - the Mill Pond; and

e - the mine shaft, the Backfill Raise, or the Portal.

B. WATERLEVEL ELEVATIONS

Waterlevel elevations determined in the minelmill area during 1992 are listed in Table 3, and illustrated by Figures 2B, 3A, and 3B. Figure 2B shows the waterlevels for the various sample sources on 12 July 1992. It indicates that waterlevel decreases from M13 to M57; that waterlevels in the former M11, the Mill Pond, and M38 are relatively similar; that from there waterlevels decrease progressively to WHS to BRP to M18 to BRC/PRC to BR13 and PRS, and finally to Confederation Lake and the subaqueous seeps. In M14, in the small valley carrying the overflow from the Mill Pond, the waterlevel is slightly lower than that of the WH Seep

Seasonal variations in waterlevels for the piezometers in the minelmill area, during the period from October 1986 to August 1992, are shown in Figure 3A. The graphs indicate that the highest measured waterlevels in all these piezometers occurred

during the spring of 1990 (it should be noted that no measurements were recorded during 1991, and that the few waterlevel measurements during 1992 may have missed the maximum waterlevels). During most of the period of record, waterlevels decrease from M13 to M57 (to the former M11) to M38 to M18; the waterlevel in M14 was intermediate between the levels in M38 and M18.

The few waterlevel measurements made during 1992 in ponds, seepages and mine structures are illustrated by Figure 3B. The plot again indicates that the waterlevels decrease from MP to WHS to BRP to BRC/PRC to PRS. Waterlevels below the Backfill Raise Cap and below the Portal Raise Cap are virtually the same; they are likely to represent the waterlevel in the mine.

Distances from the tailings spill site and from Mill Pond to Confederation Lake are about 260 m; distances from those points to Boomerang Lake are about 335 m and about 450 m, respectively. This means that, where bedrock does not obstruct flow, subsurface water would preferentially move towards Confederation Lake, due to a stronger gradient.

Depths to bedrock determined during piezometer installation were: M11 - 25.0 ft; M18 - 24.7 ft; and M38 - 18.5 ft. Only a few scattered bedrock depths are shown on the bedrock contour map by Morton Geotech (their Drawing #8). Additional depth-to-bedrock data might be available from exploration drillholes.

C. VARIATIONS IN CHEMICAL COMPOSITION WITH TIME

Figures 4A to 4D show the variations in the concentrations of S, Fe, Mn, Zn, Ca, and Cu (if present) in samples collected from piezometers M14, M18, M38, and M57 in the mine/mill area in the period from November 1986 to August 1992. With the exception of [Mn] in M14, and possibly [Fe] in M57, the sulfur and metal concentrations show a small long-term decrease. Compared to the other

piezometers, the water in M14 was high in both zinc and copper; this has been interpreted as being due to blowing metal-sulfide dust from the mill site.

Figures 4E and 4F show the relationship between [Fe] and [S] for samples from all piezometers at South Bay, and for samples from other (surface-water) sources, respectively. The location of a number of the points in Figure 4E between the lines for pyrite and pyrrhotite suggests that at least some of the Fe and S has been derived from the oxidation of pyrrhotite; there is no indication of this in Figure 4F. It is likely that the low Fe content of most of the samples in Figure 4F reflects a higher degree of loss of Fe due to aeration.

Figures 5A to 5G show the variations in metal and sulfur concentrations during the (spring and) summer of 1992 in samples from several of the other sources in the mine/mill area (from Tables **2** and 3B).

The samples from the **Warehouse Seep** (Figure 5A) show minor dilution (decrease in S and Ca), and significant depression of the metal concentrations which may be related to an increase in pH. [Fe] reacts anomalously.

The samples from the **Backfill Raise Cap** (Figure 5B) also show minor dilution (decrease in S and Ca), and depression of metal concentrations.

The samples from the **Mill Pond** (Figure 5C) show minor dilution between 24 March and 13 July, more dilution between 13 July and 18 July, and a recovery between 18 July and 14 August. Both the initial decrease and the subsequent increase were largest for [Fe].

The samples from the **BR13 Seep** (Figure 5D) show dilution between 13 July and 16 July, followed by a recovery between 16 July and 14 August. Again, the effects were largest for [Fe].

The samples from the **CI3-30 Seep** (Figure 5E) show the effects of dilution from 24 March to 15 July, followed by a recovery between 15 July and 14 August. [Fe] again showed the largest effects.

The samples from the **Portal Raise Seep** (Figure 5F) show and increase in concentrations (except [Ca]), between 13 July and 16 July, followed by decreases in concentration between 16 July and 14 August. Fe concentrations showed the largest effects.

The samples from the **Portal Raise Cap** (Figure 5G) show increases in concentration between 14 July and 14 August. [Fe] showed the largest effect.

D. GEOCHEMICAL CALCULATIONS

In early October 1992 it was suggested that geochemical calculations, using WATEQ4F and NETPATH, should be carried out to try and shed more light on the development of the water chemistry in the area, and on the potential source(s) of the heavy-metal contamination. For this purpose all available analyses for samples from the area were evaluated for their possible use in such calculations. It was found that some of the required data, including field measurements of water temperature, pH and Eh, were missing for a number of the analyses.

MISSING DATA

Field data on temperature, pH, and Eh are not available for the 34 samples of March 1992, and no alkalinity concentrations were determined for those samples. Similarly, field data are not available for 18 of the 51 samples of July 1992, and alkalinity (or TIC) concentrations were determined, in the laboratory, on only 17 of the 51 samples. Finally, field data are not available for 12 of the 29 samples of August 1992, and alkalinity concentrations were determined, in the laboratory, on only 12 of the 29 samples.

TIC values were given for eight of the July 1992 samples, all with pH values above 4.5, and not for any of the samples with pH values below 4.5, for which such information would have been very useful.

[Cl] data were not available for any of the 1992 samples; data on phosphate and nitrate concentrations were very limited.

In addition to the above, Table 2 lists a number of samples from "seepages in the Backfill Raise area", collected in July '87, May '89, and in May, June, July and September '91. Only partial analyses were made available for the samples collected in May 1989, and on those collected on the 4 dates in 1991.

Table 4 indicates the sources of the values of T, pH, Eh, and alkalinity (or TIC) for the selected sample analyses that were used in the geochemical modelling.

Appendix A presents the analytical data for each of the selected samples used in the modelling. It includes an analysis of "distilled water"; an estimated analysis for "precipitation" in the area; and an analysis of water from a pond in a gravel pit outside the mine/mill area, to represent "uncontaminated" groundwater. The concentration values for "precipitation" were derived from geometric mean monthly values for 1981-1983, shown in Table 5 (from "Summary Statistics", Acid Precipitation Study, Ontario Ministry of Environment).

DEGREES of SATURATION (from WATEQ4F)

In order to determine which minerals were likely to be dissolved by, or precipitated from, any of the selected water samples, the speciation program WATEQ4F (version 2.0, U.S.Geological Survey Open-File Report 91-183) was used to calculate saturation indices (SI values) for any minerals containing a combination of the elements determined during chemical analysis of the water samples. This information enabled the selection of the most likely dissolved and precipitated

minerals to be used in the program NETPATH (version 1.5, U.S.Geological Survey Water-Resources Investigation Report 91-4078), as described in the next section of this report.

It was assumed that pyrite, chalcopyrite, and sfalerite were the minerals most likely to be dissolved by waters in the mine/mill area. Appendix B lists the calculated positive saturation indices (SI) with respect to the most likely precipitate minerals, for each of the selected samples. It should be pointed out that a positive SI value for a particular water with respect to a particular mineral means (1) that the water is supersaturated with respect to that mineral; (2) that the water is not likely to dissolve more of that mineral (if available); and (3) that the mineral may be precipitated from the water. If supersaturation is shown with respect to more than one mineral containing the same elements, then the mineral showing the highest SI value is most likely to precipitate.

It should also be pointed out that due to the lack of data on the concentrations of carbon species, chloride, nitrate and phosphate, all carbonate, chloride, nitrate and phosphate minerals had to be omitted from consideration.

The main observations from the WATEQ4F results are:

1. All samples containing Ba showed supersaturation with respect to **barite.**
2. All samples containing Cu showed supersaturation with respect to **cuprous ferrite.**
3. All samples containing Fe showed supersaturation with respect to **goethite** and **hematite.**
4. All samples containing Al showed supersaturation with respect to **annite;** some also showed supersaturation with respect to **boehmite** and **gibbsite;** the samples from BRC, PRS, and the gravel-pit pond also showed supersaturation with respect to one or more **clay minerals.**

5. All samples except that from the gravel-pit pond ([Si]=0.34mg/L) showed supersaturation with respect to **quartz.**
6. All samples except those from WHS, Mill Pond, and BR13, showed supersaturation with respect to $ZnSiO_3$. The July and August samples from WHS, Mill Pond, and BR13 were undersaturated with respect to this mineral.

The use of laboratory measurements of Eh may of course have distorted the extent of goethite/hematite supersaturation, whereas the use of laboratory measurements of pH may have distorted the extent of supersaturation with respect to pH-sensitive minerals, including goethite, hematite, boehmite, and gibbsite.

DISSOLUTION, PRECIPITATION, MIXING. and DILUTION (using NETPATH)

Appendix C presents the input and the results of the NETPATH modelling for each of the selected samples.

As pointed out earlier, due to lack of information on the concentrations of carbonate, chloride, nitrate, and phosphate in the samples, these ions, as well as the mineral species to which they would contribute, had to be omitted from consideration. This will have tended to limit the reliability of the results.

For some of the sample sources, precipitation (rain or snowmelt) or uncontaminated groundwater was assumed to be the original input ("Initial Source" in Appendix C), and NETPATH was used to determine how much of which minerals had to be dissolved (or precipitated) to derive the final water ("Final Source"), as sampled. For some of the other sources, a mixture of contaminated and uncontaminated waters ("Initial Source 1" and "Initial Source 2") was assumed as input, and NETPATH was used to determine the probable mixing ratio, as well as possible mineral dissolution and precipitation. Finally, for some of the sample sources two samples taken before and after dilution by rain or snowmelt ("Initial Source" and "Final Source") were used in NETPATH to determine the dilution ratio.

The waterlevel relationships (Figure 3B) suggested that M57, M38, (M11), WHS, and MP (and probably BRP and M18) receive their heavy-metal contamination from near-surface sulfide sources on the mine/mill site; that BRC and PRC both contain mine water; and that BR13, C13-30, and PRS discharge water with progressively smaller fractions of heavy-metal contaminated water.

The WHS water can be derived from either precipitation (Appendix C-1) or uncontaminated groundwater (Appendix C-2 and C-3) through dissolution of oxygen, sfalerite, pyrite, minor chalcopyrite, and some felspar, and precipitation of goethite (or hematite), silica, and gibbsite.

The BRC water of **14** July can be derived from either precipitation (Appendix C-4) or uncontaminated groundwater (Appendix C-5) through dissolution of somewhat smaller amounts of oxygen, sfalerite, pyrite, a trace of chalcopyrite, and some felspar, and precipitation of goethite, silica, and gibbsite.

The PRC water of 14 August can be derived from a mixture of some **4%** WHS water and 96% uncontaminated groundwater (Appendix C-6) or from a mixture of about 5% BRC water with 95% uncontaminated groundwater (Appendix C-7), accompanied by dissolution of minor amounts of oxygen and felspar, and precipitation of minor amounts of zinkite, goethite, and copper sulfate (or, more likely, carbonate). The decreases in Ca/S and Ca/Zn ratios, and increases in sulfur and heavy-metal concentrations between 14 July and 14 August indicate that the percentage of contaminated water in PRC water is increasing.

The PRS water of 13 July can be derived from a mixture of some 14% WHS water and 86% uncontaminated groundwater (Appendix C-8), accompanied by dissolution of minor amounts of oxygen, felspar, and chalcopyrite, and precipitation of zinkite, and a minor amount of goethite. Between 13 July and 14 August, the PRS water was likely diluted by a factor of about 1.5, accompanied by dissolution of trace

amounts of oxygen and pyrite, and precipitation of some zinkite and trace amounts of copper sulfate and MnOOH (Appendix C-9). The decrease in the percentage of WHS water between 13 July and 14 August, is indicated by decreases in metal concentrations and a change in the Ca/S ratio (Figure 5F). The peak in sulfur and metal concentrations on 16 July, shown in Figure 5F, may well reflect the discharge of a slug of contaminated water, pushed by infiltrating rainwater.

The MP water can be derived from precipitation (Appendix C-10) through dissolution of oxygen, sfalerite, pyrite, and some chalcopyrite and felspar, and precipitation of goethite, and some silica. Between 13 and 18 July, the MP water was likely diluted by a factor of about 1.3, accompanied by dissolution of a trace amount of oxygen, and precipitation of some zinkite and trace amounts of copper sulfate and MnOOH (Appendix C-11). Similarly, it is likely that the sample of 14 August was a mixture of about 90% of the MP water of 13 July and 10% precipitation, accompanied by dissolution of a trace amount of silica, and precipitation of zinkite, some gibbsite, and a trace amount of copper sulfate or possibly carbonate (Appendix C-12). "Blue" holes observed in the Mill Pond in mid-July may well have reflected some precipitation of secondary copper minerals.

The BR13 water can be derived from a mixture of some 43% BRC water and 57% uncontaminated groundwater (Appendix C-13), accompanied by dissolution of minor amounts of oxygen, pyrite, and felspar, and precipitation of zinkite, and minor amounts of MnOOH and cuprous-ferrite. Between 13 and 16 July the PRS water was likely diluted by a factor of about 2.2, accompanied by dissolution of trace amounts of oxygen and sfalerite, and precipitation of trace amounts of goethite and MnOOH (Appendix C-14).

The C13-30 water can be derived from a mixture of some 41% BRC water and 59% uncontaminated groundwater (Appendix C-15), accompanied by dissolution of minor amounts of oxygen and pyrite, and precipitation of zinkite, and minor amounts of

MnOOH, cuprous-ferrite, and silica. Between **15** July and 14 August the PRS water recovered from a likely dilution by a factor of about 2.0, which had been accompanied by dissolution of trace amounts of oxygen, sfalerite, and MnOOH, and precipitation of a trace amount of goethite (Appendix C-16).

CONCLUSIONS / RECOMMENDATIONS

The drainage ditch from the BRC site to Boomerang Lake, currently under construction, is likely to divert a significant portion of the contaminated seepage that may at present be directed from the minelmill area towards Confederation Lake.

Perforation of the Backfill Raise at the level of the new drainage ditch would limit the maximum possible waterlevel in the mine, and this would in turn reduce the potential for discharge of highly contaminated water from the mine, through the Portal area, to Confederation Lake.

Lowering the water table in any of the sulfide-bearing materials in the subsurface of the minelmill area may of course enhance oxidation of the metal-sulfides contained in them. A further point that should be checked is the potential effect of watertable drawdown on vegetation in the vicinity of the drainage ditch.

Although removal of spilled tailings (and any other sulfide-bearing materials) from the minelmill area to the tailings area could eliminate significant potential sources of contamination, the disturbance created by the removal operation itself could cause increased contamination of subsurface waters in the site, at least temporarily.

In early October it was suggested that water samples should be collected from all significant inflows (seeps) during excavation of the ditch. If at all possible, pH, Eh, and temperature of the samples should be measured in the field; samples should be

properly preserved for analysis; and they should be forwarded to Boojum Research Limited for laboratory analysis.

In addition, if significant flows with elevated Zn and/or Cu concentrations are encountered, approximate discharge rates should be determined to allow an estimate of the additional Zn and Cu loadings to Boomerang Lake.

The above information on water chemistry and flow rates will be needed to allow a proper "post-mortem" analysis of the ditch project, particularly if the ditching does not solve the seepage problem completely.

R. O. van Everdingen
27 November 1992

Figure 1-A.
Survey Locations July 1992

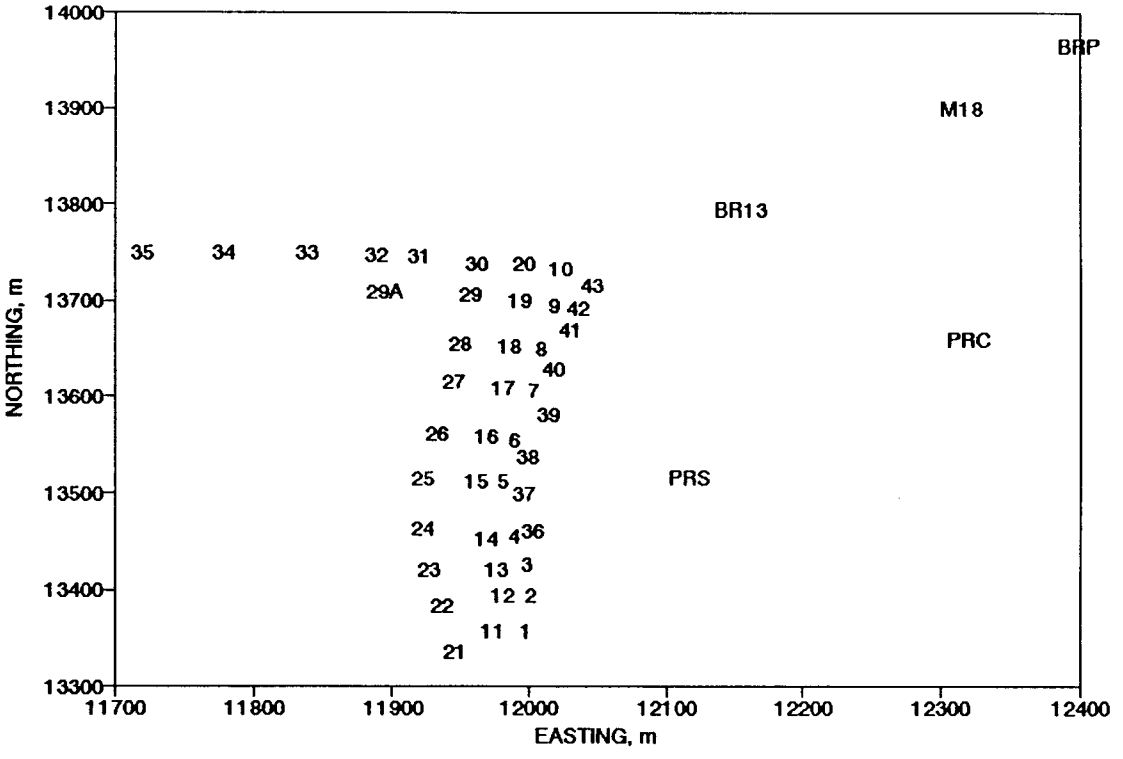


Figure 1-B.
Survey Depths (m), July 1992

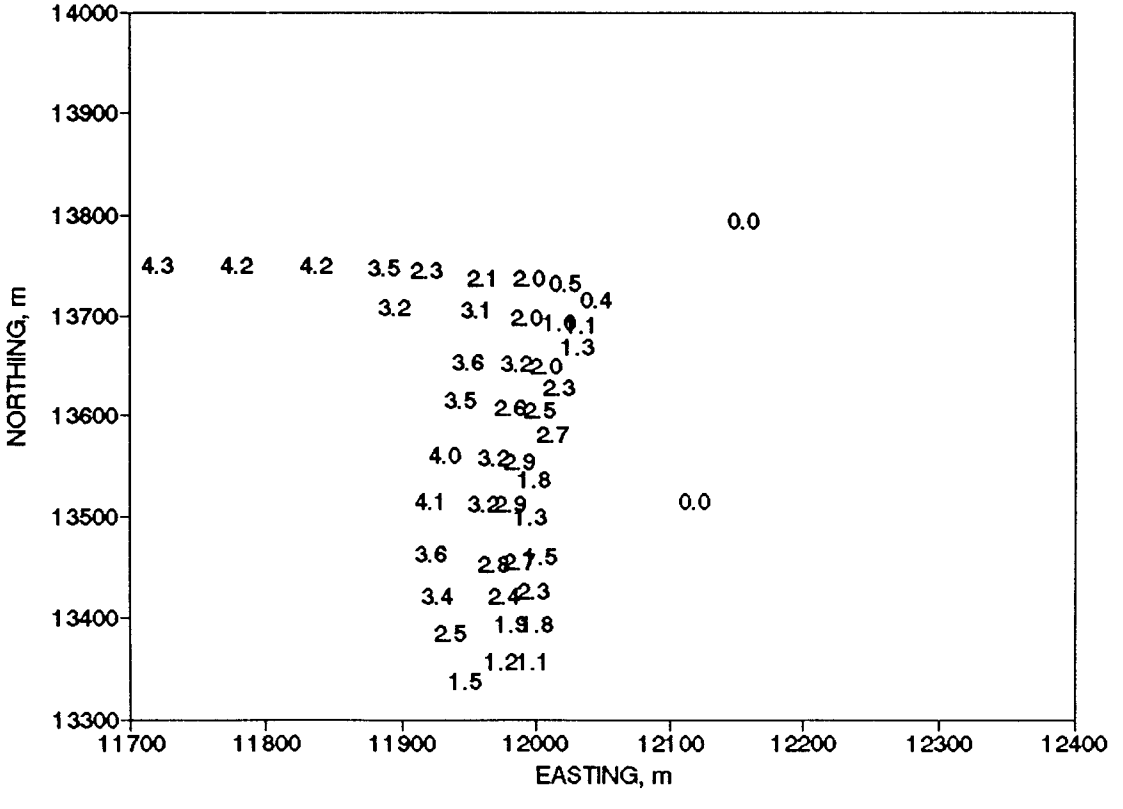


Figure 1-C.
Conductivity Survey July 1992

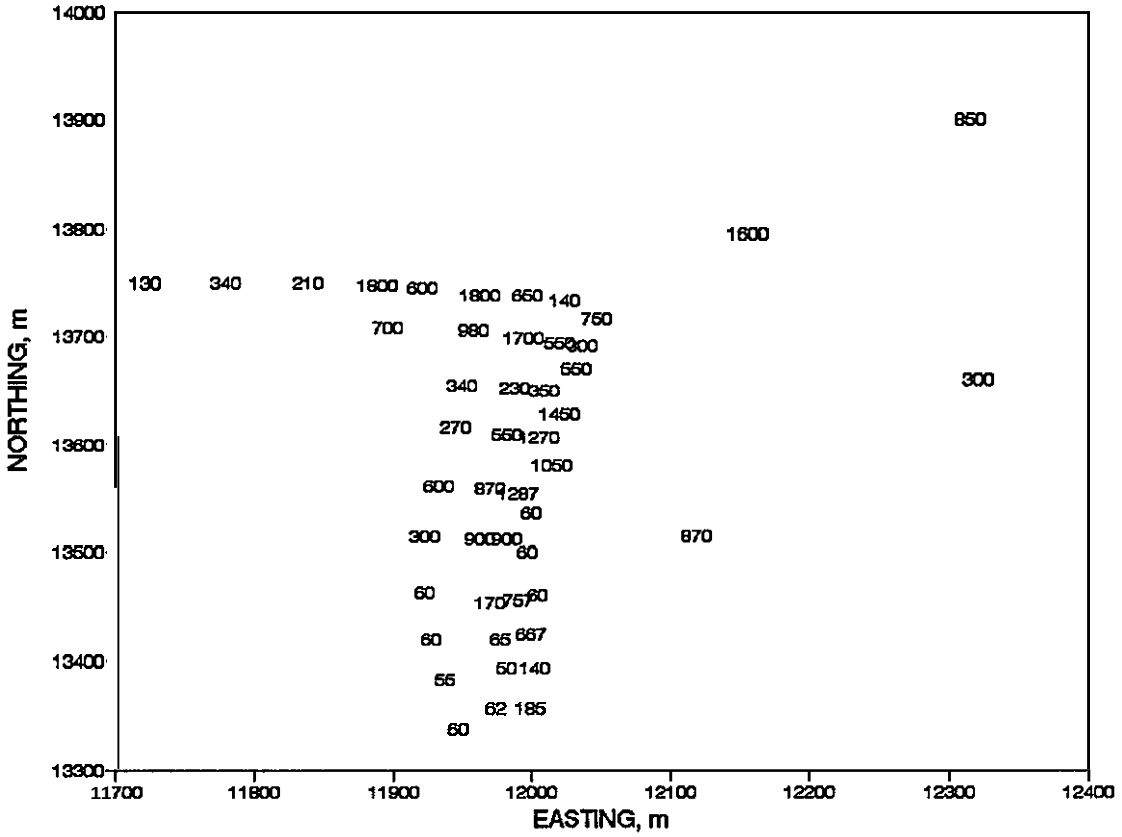


Figure 1-D.
pH Survey July 1992

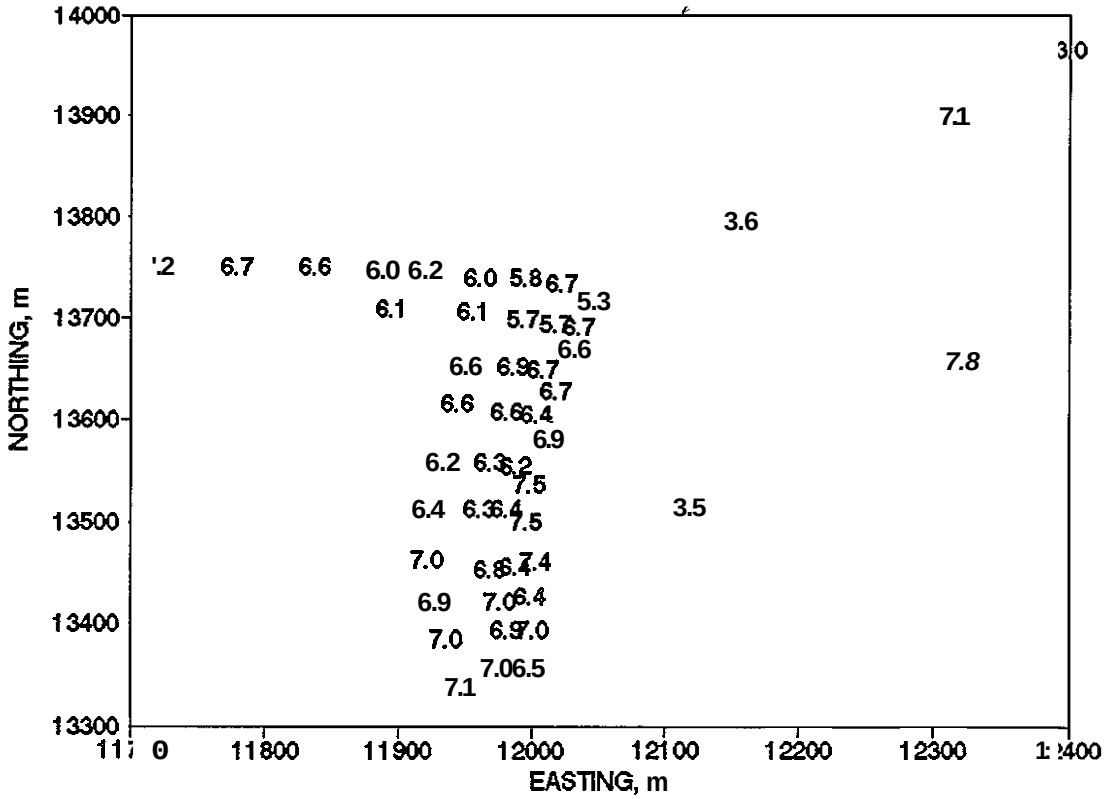


FIGURE 2-A.
Zinc Concentrations, 12 July 1992

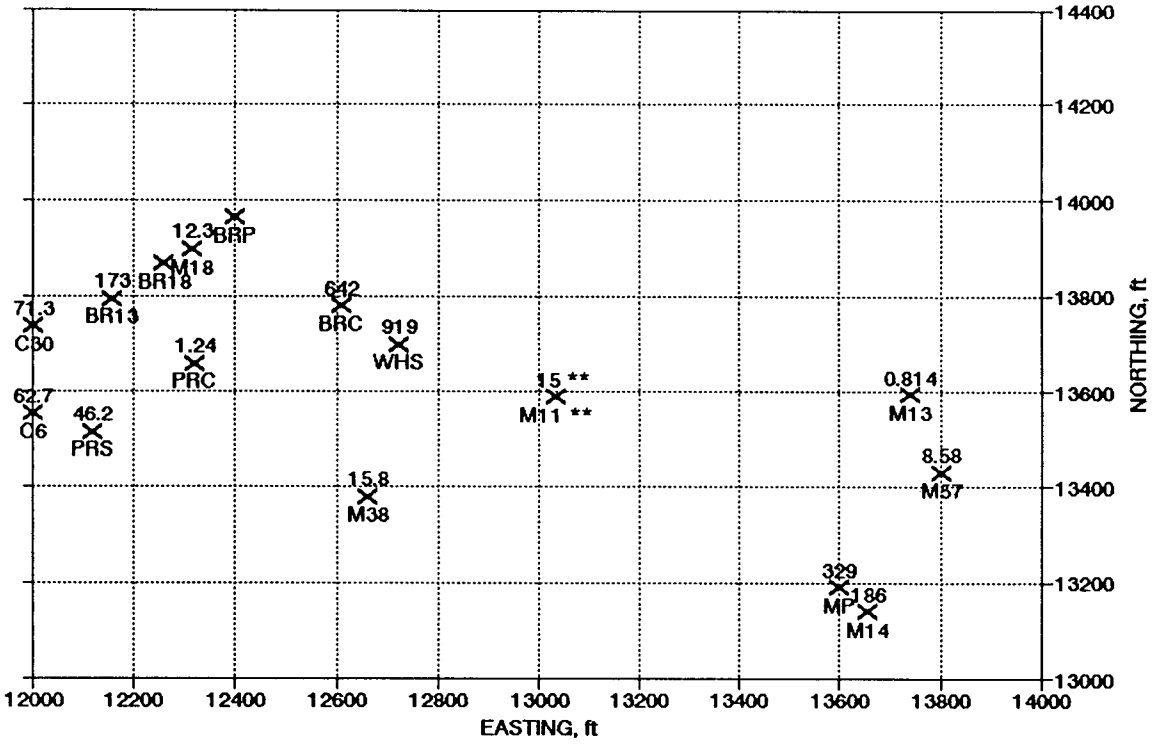


FIGURE 2-B.
Waterlevels, 12 July 1992

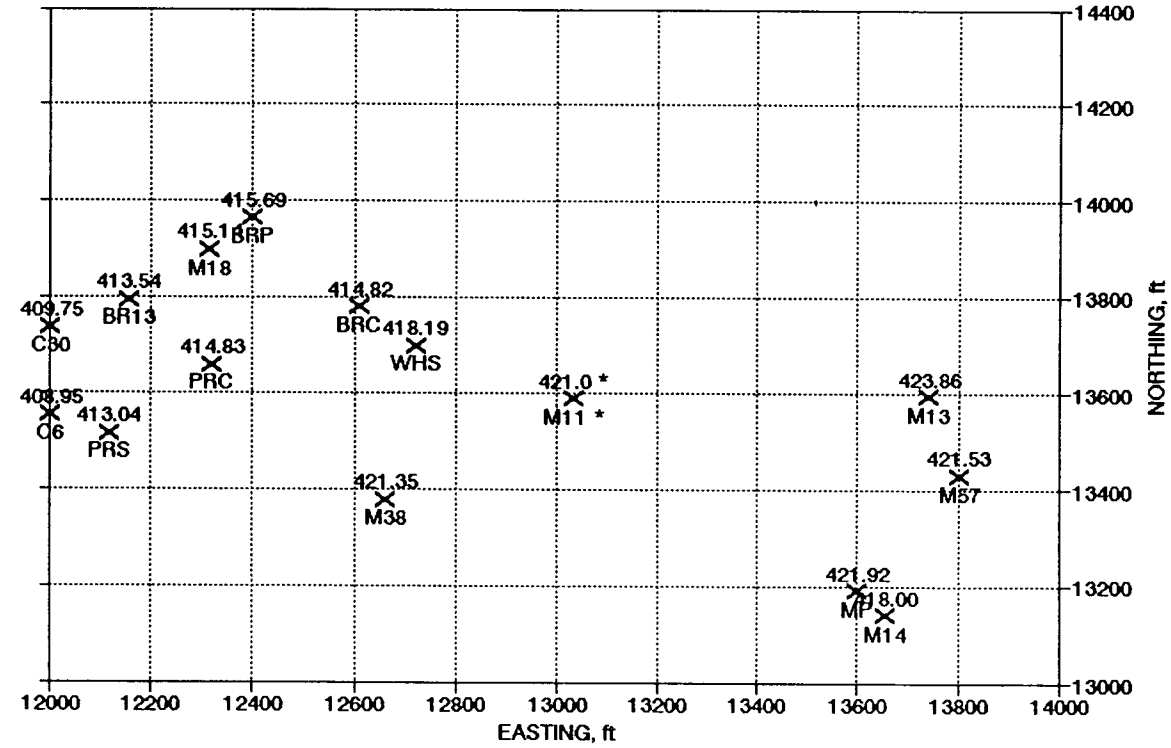


FIGURE 3-A.
Mine-Site Piezometers

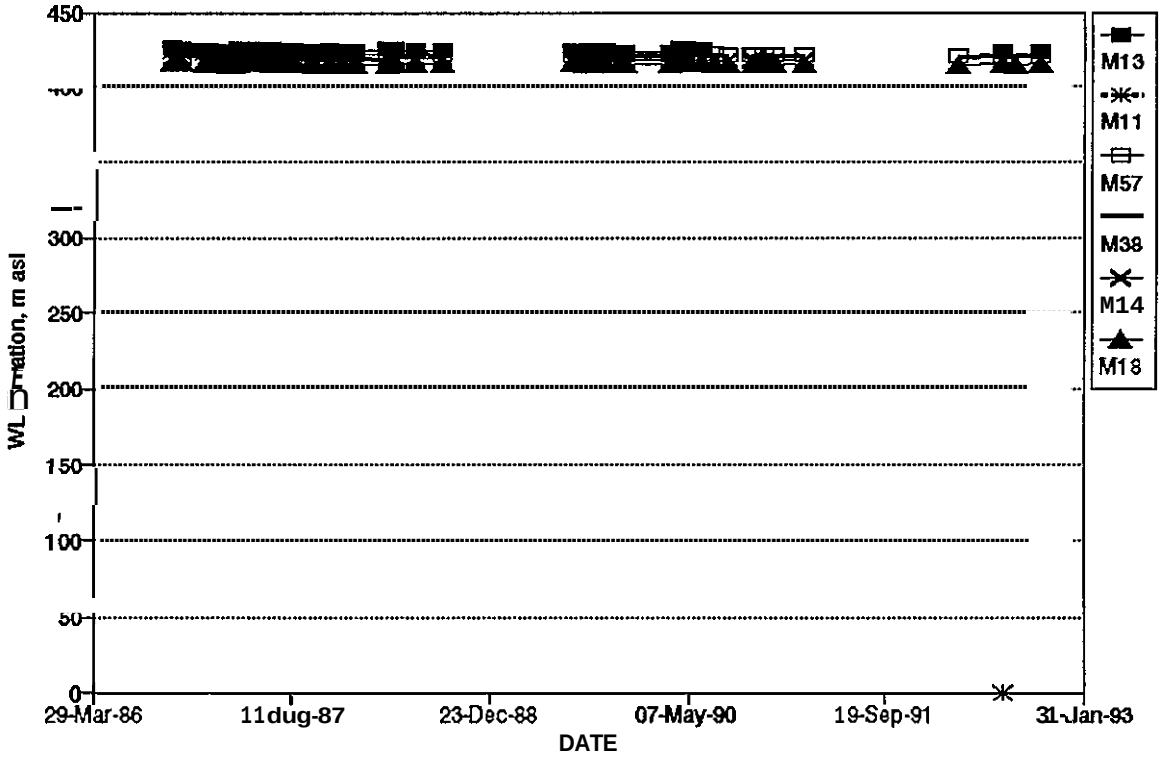
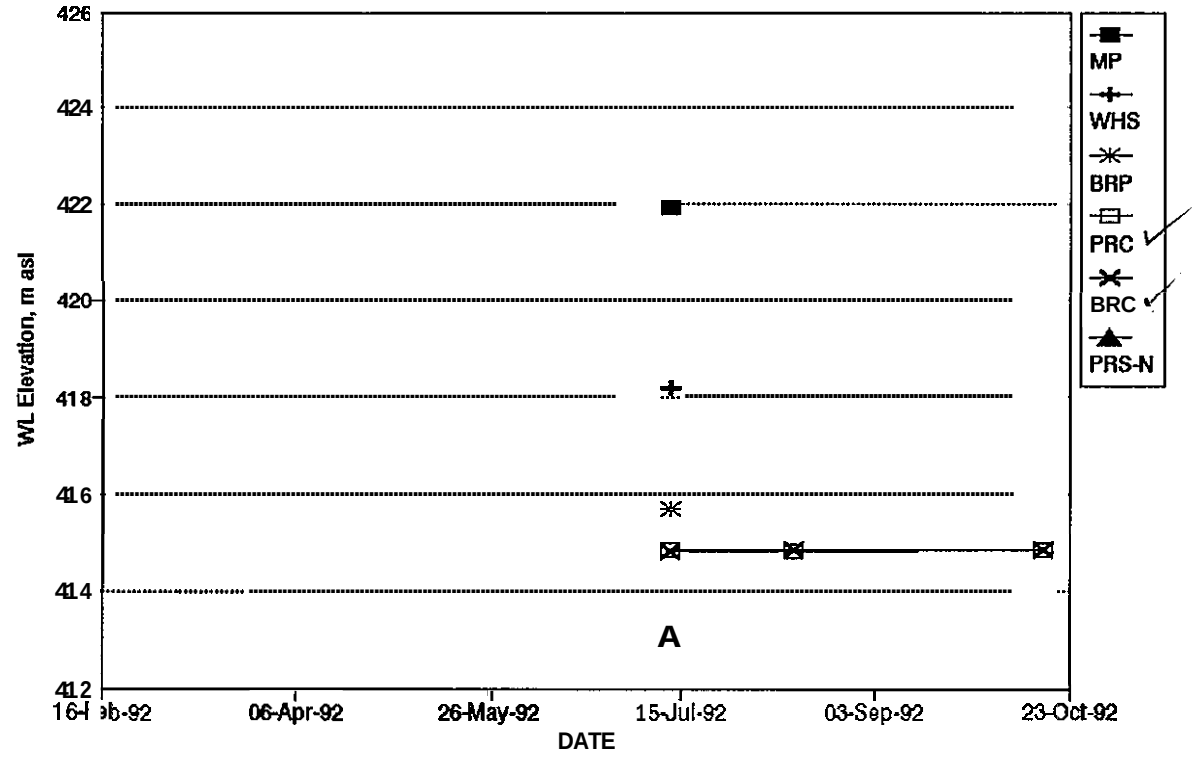


FIGURE 3-B.
OTHER SOURCES



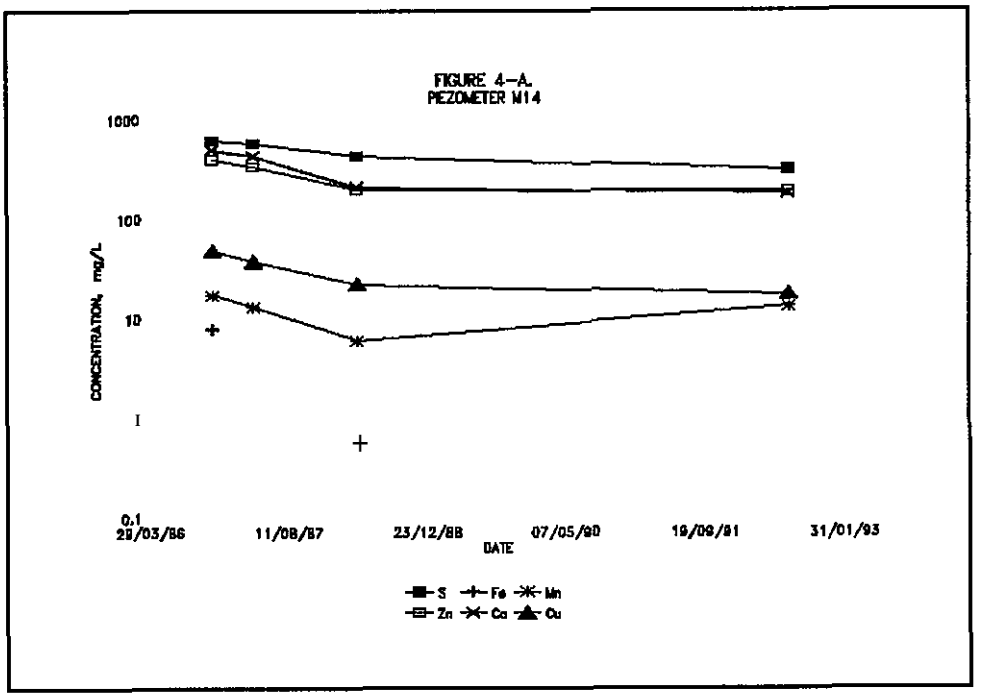


FIGURE 4-A.
PIEZOMETER M14
1000
100
10
1
0.1
CONCENTRATION, mg/L
29/03/86
11/08/87
23/12/88
07/05/90
19/09/91
31/01/93
DATE
S
Fe
Mn
Zn
Ca
Cu

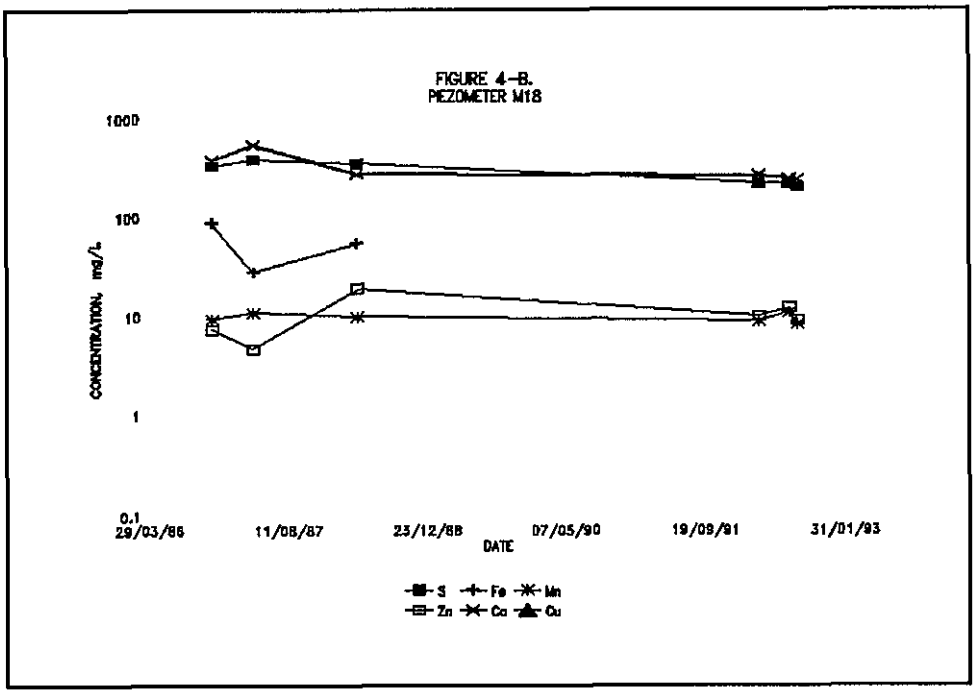


FIGURE 4-B.
PIEZOMETER M18
1000
100
10
1
0.1
CONCENTRATION, mg/L
29/03/86
11/08/87
23/12/88
07/05/90
19/09/91
31/01/93
DATE
S
Fe
Mn
Zn
Ca
Cu

FIGURE 4-C.
PIEZOMETER M38

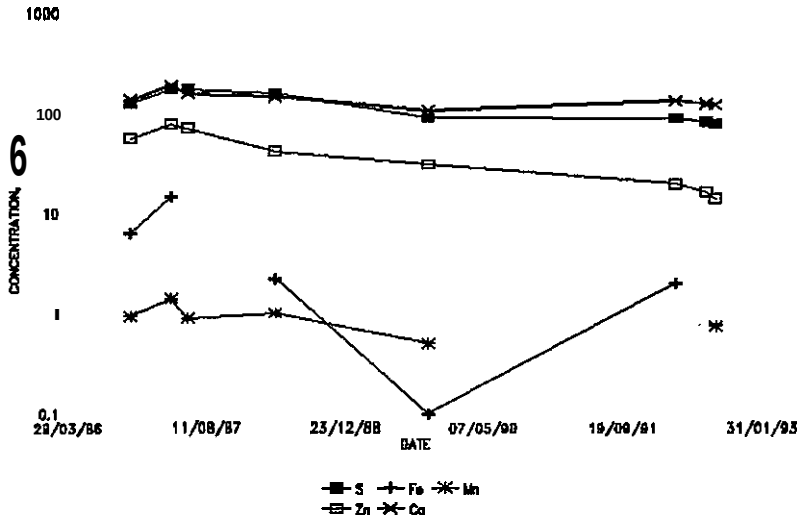
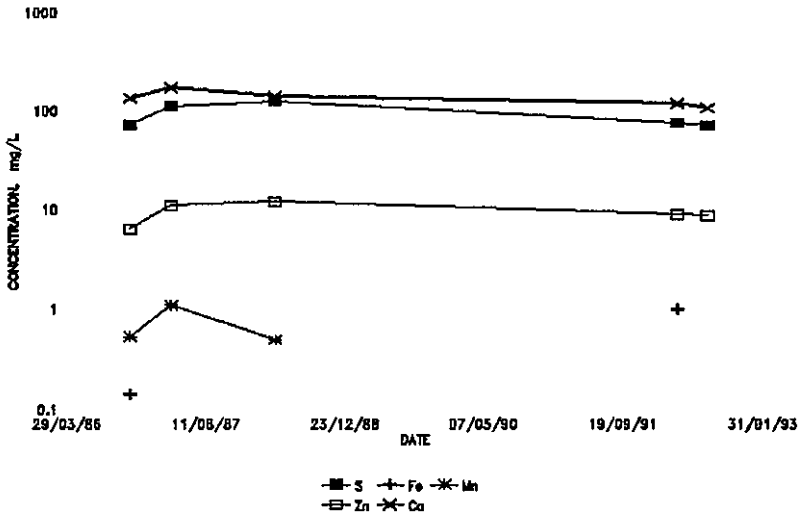


FIGURE 4-D.
PIEZOMETER M57



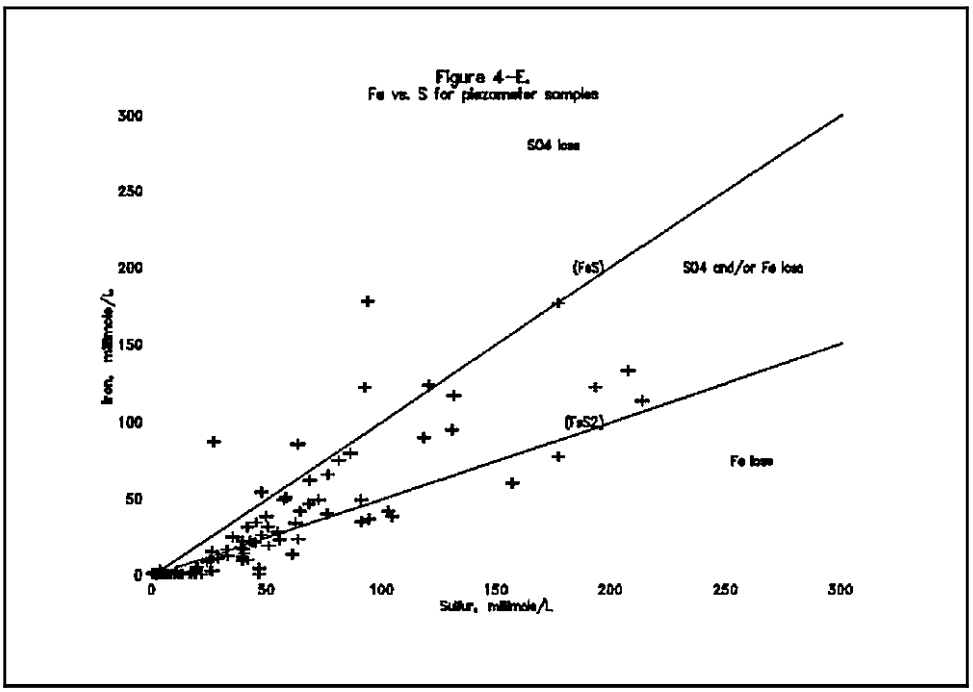


Figure 4-E.
Fe vs. S for piezometer samples
SO4 loss
(FeS)
SO4 and/or Fe loss
(FeS2)
Fe loss
Iron, millimole/L
Sulfur, millimole/L
0
50
100
150
200
250
300

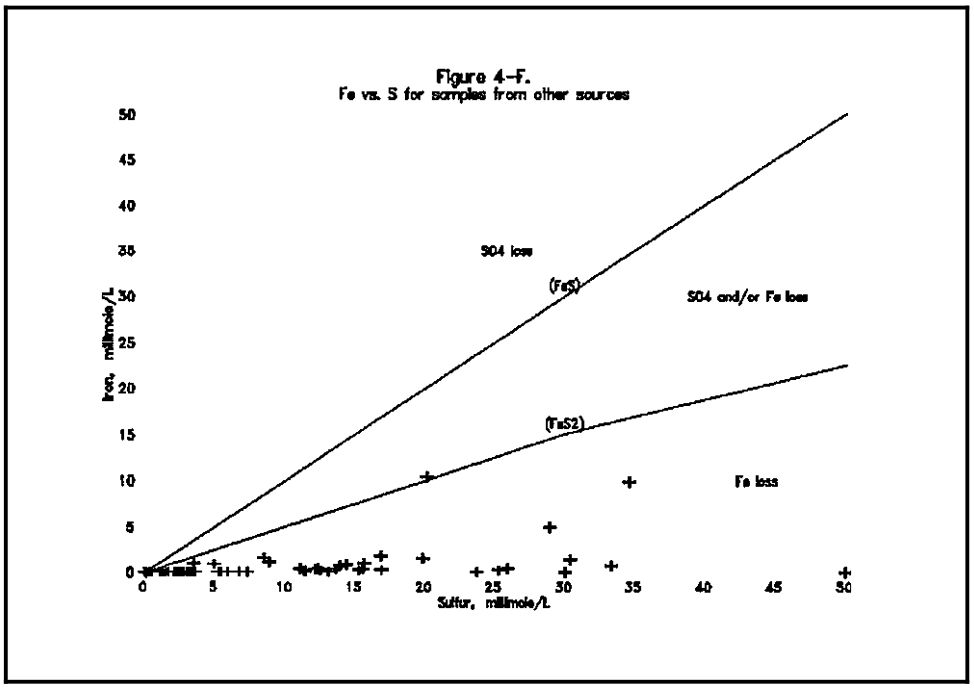


Figure 4-F.
Fe vs. S for samples from other sources
SO4 loss
(FeS)
SO4 and/or Fe loss
(FeS2)
Fe loss
Iron, millimole/L
Sulfur, millimole/L
0
5
10
15
20
25
30
35
40
45
50

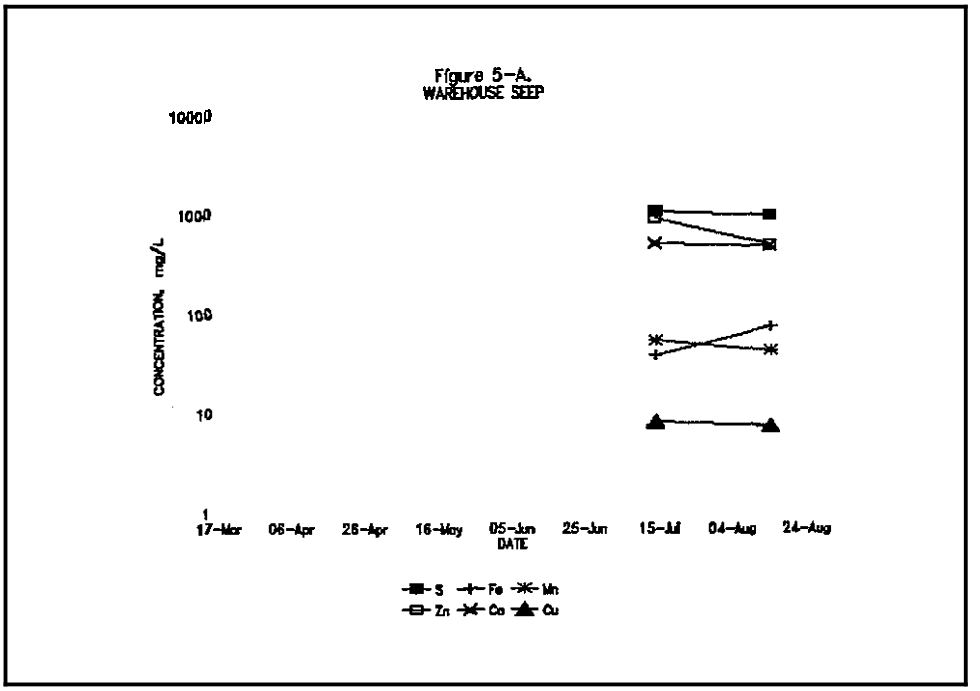


Figure 5-A.
WAREHOUSE SEEP
10000
1000
100
10
1
CONCENTRATION, mg/L
17-Mar
06-Apr
26-Apr
16-May
05-Jun
25-Jun
15-Jul
04-Aug
24-Aug
DATE
S
Fe
Mn
Zn
Co
Cu

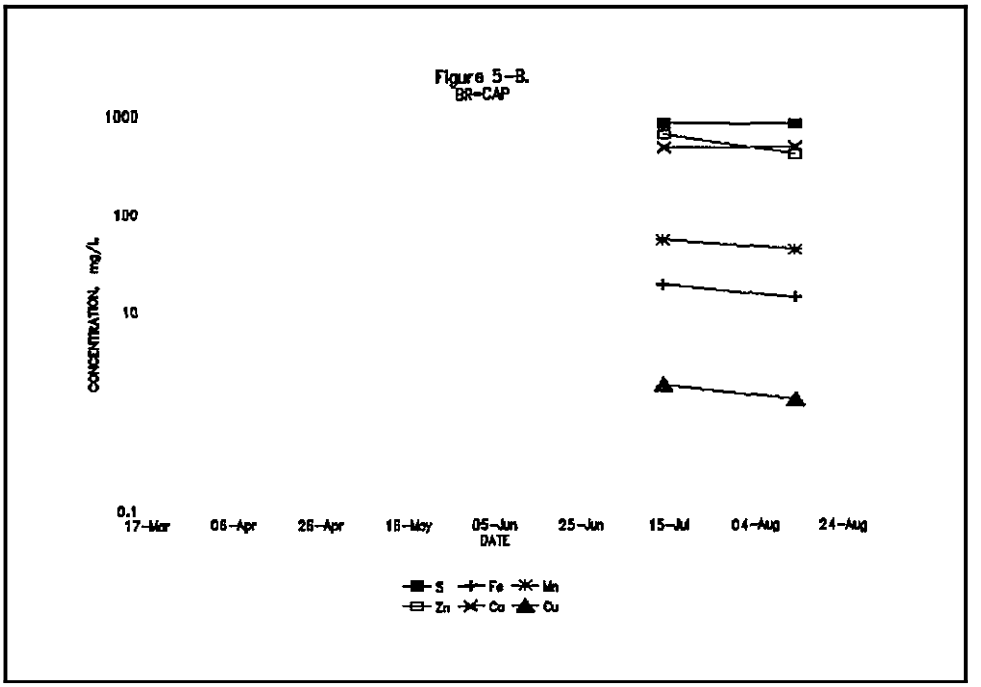


Figure 5-B.
BR-CAP
1000
100
10
0.1
CONCENTRATION, mg/L
17-Mar
06-Apr
26-Apr
16-May
05-Jun
25-Jun
15-Jul
04-Aug
24-Aug
DATE
S
Fe
Mn
Zn
Co
Cu

Figure 5-C.
MILL POND

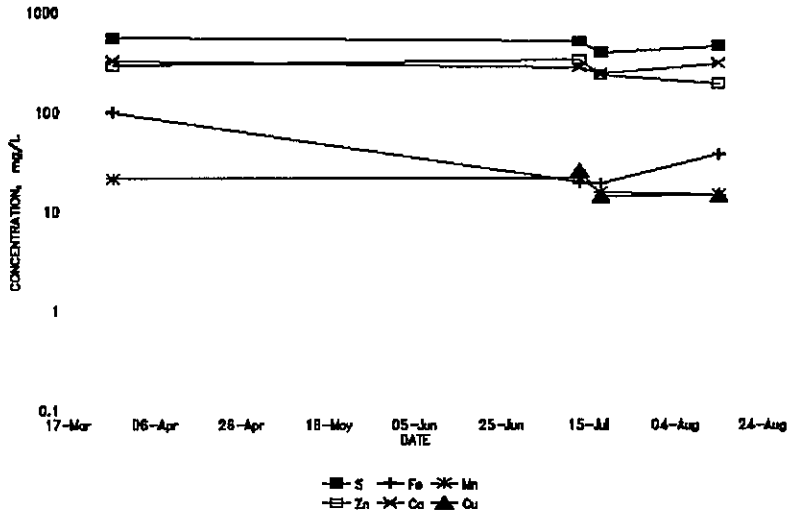


Figure 5-D.
BR-13

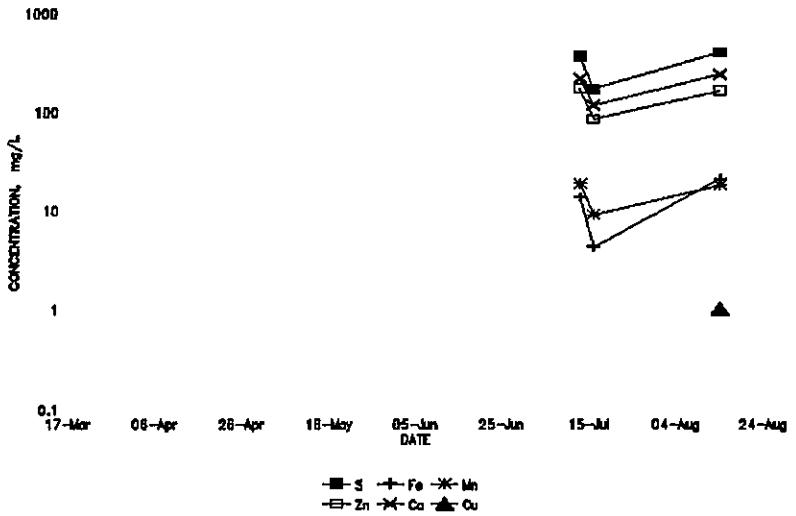


Figure 5-E.
C13(-30)

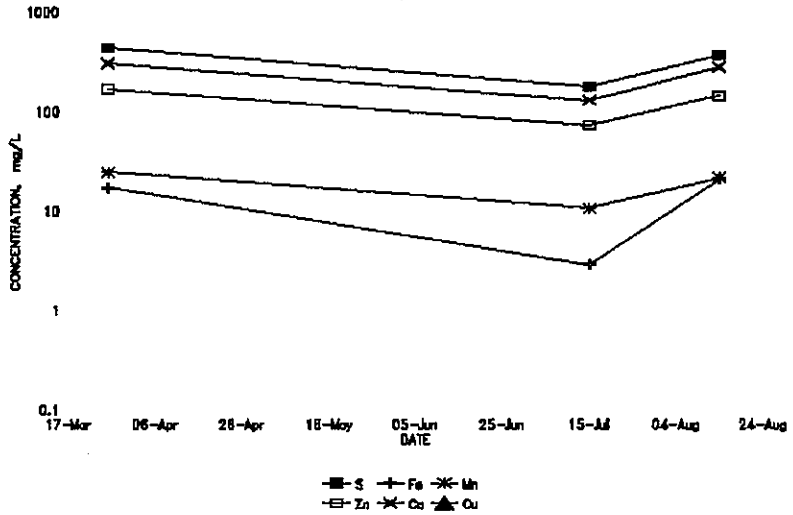
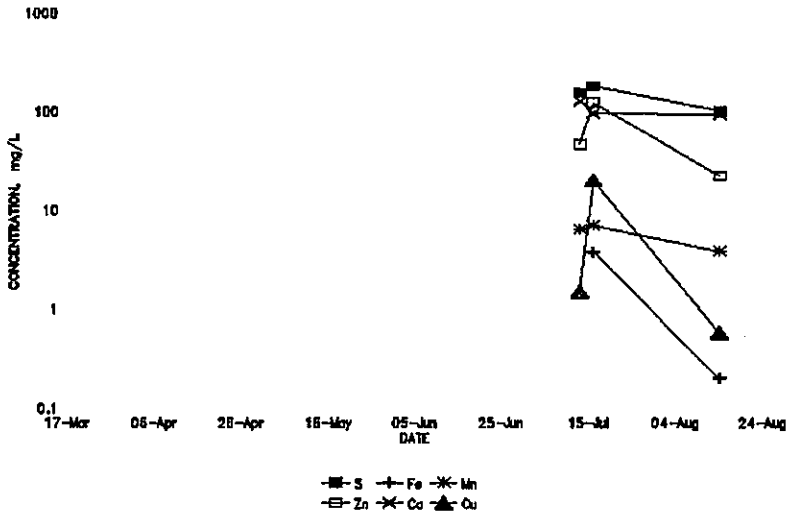


Figure 5-F.
PR-SEEP



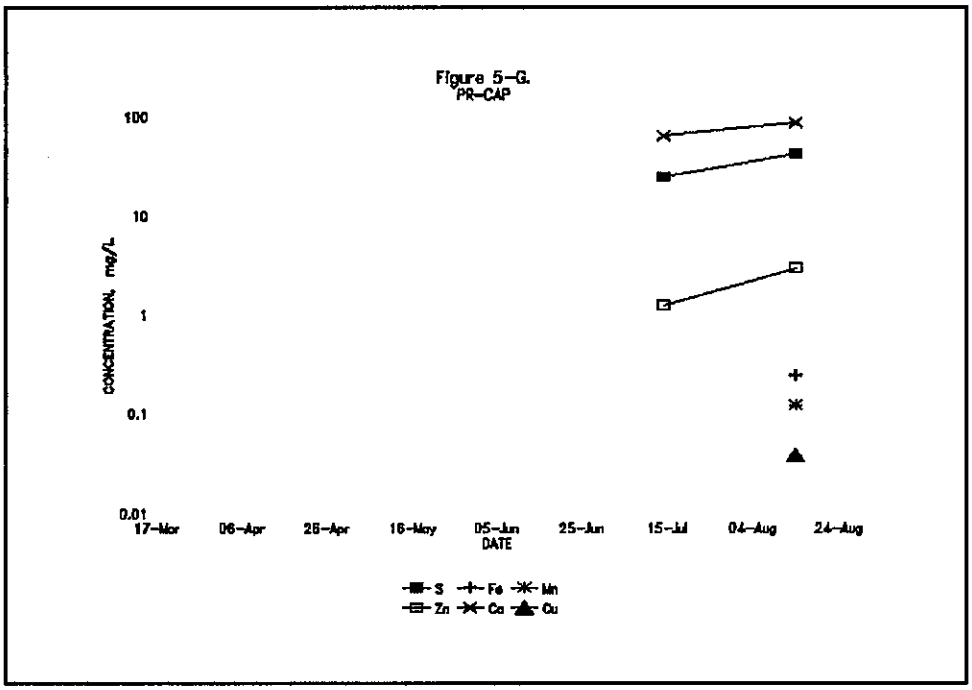


Figure 5-G.
PR-CAP
100
10
1
0.1
0.01
CONCENTRATION, mg/L
17-Mar
06-Apr
26-Apr
16-May
05-Jun
25-Jun
15-Jul
04-Aug
24-Aug
DATE
S
Fe
Mn
Zn
Co
Cu

CONFEDERATION LAKE JULY 1992 TRANSECTS

Point #	COORDINATES, ft EASTING ft	NORTHINQ ft	DEPTH, m z	COORDINATES, m W-E m	S-N m
BRC	12610	13781	0.0	330.0	142.5
WH8	12720	13700	0.0	363.8	117.0
M38	12660	13380	7.1	328.5	19.5
BRP	12400	13965	0.0	240.0	199.5
M18	12315	13900	8.7	228.8	179.3
PRC	12320	13660	0.0	228.8	103.5
BR13	12155	13795	0.0	174.0	139.5
PRS	12118	13515	0.0	160.5	48.0
36	12003	13460	1.5	132.0	42.8
37	11996	13500	1.3	129.8	54.8
38	11998	13537	1.8	130.5	66.0
39	12013	13581	2.7	135.0	79.5
40	12018	13628	2.3	136.5	93.8
41	12030	13669	1.3	140.3	106.5
42	12035	13692	1.1	141.8	113.3
43	12045	13716	0.4	144.8	120.8
1	11998	13357	1.1	130.5	11.3
2	12001	13394	1.8	131.3	22.5
3	11998	13426	2.3	130.5	32.3
4	11988	13455	2.7	127.5	41.3
5	11981	13512	2.9	125.3	58.5
6	11988	13554	2.9	127.5	71.3
7	12003	13605	2.5	132.0	87.0
8	12008	13650	2.0	133.5	100.5
9	12018	13694	1.0	136.5	114.0
10	12023	13733	0.5	138.0	126.0
11	11974	13357	1.2	123.0	11.3
12	11981	13394	1.9	125.3	22.5
13	11976	13421	2.4	123.8	30.8
14	11969	13453	2.8	121.5	40.5
15	11961	13512	3.2	119.3	58.5
16	11969	13559	3.2	121.5	72.8
17	11981	13608	2.6	125.3	87.8
18	11986	13652	3.2	126.8	101.3
19	11993	13699	2.0	129.0	115.5
20	11996	13738	2.0	129.8	127.5
21	11946	13337	1.5	114.8	5.3
22	11937	13384	2.5	111.8	19.5
23	11927	13421	3.4	108.8	30.8
24	11922	13463	3.6	107.3	43.5
25	11922	13514	4.1	107.3	59.3
26	11932	13561	4.0	110.3	73.5
27	11944	13615	3.5	114.0	90.0
28	11949	13655	3.6	115.5	102.0
29	11956	13706	3.1	117.8	117.8
30	11961	13736	2.1	119.3	127.5
29A	11895	13708	3.2	99.0	118.5
31	11919	13746	2.3	106.5	129.8
32	11887	13748	3.5	96.8	130.5
33	11838	13751	4.2	81.8	131.3
34	11779	13751	4.2	63.8	131.3
35	11720	13751	4.3	45.8	131.3
C8	11570	13544	5.0	*0.0*	68.3

CONFEDERATION LAKE JULY 1992 TRANSECTS

Point #	Conductivity TOP	Conductivity HALFWAY	Conductivity BOTTOM	pH BOTTOM	Zinc mg/L
BRC			1850	5.6	642
WH8			2650	3.2	919
M38			450	6.3	15.8
BRP				3.0	
M18			850	7.1	12.3
PRC			300	7.8	1.24
BR13			1600	3.6	173
PRS			870	3.5	122
36			60	7.4	
37			60	7.5	
38			60	7.5	
39			1050	6.9	
40			1450	6.7	
41			550	6.6	
42			300	6.7	
43			750	5.3	
1	62.1	62.1	185	6.5	
2	62.1	62.2	140	7.0	
3	61.8	62.4	667	8.4	
4	62	62	757	6.4	
5	62	€3	900	6.4	
6	62	62	1287	6.2	62.7
7	61	62	1270	6.4	
8	61	55	350	6.7	
9	50	50	550	5.7	
10	60		140	6.7	
11	50	50	62	7.0	
12	50	50	50	6.9	
13	50	50	65	7.0	
14	50	50	170	6.8	
15	50	50	900	6.3	
16	50	50	870	6.3	
17	50	50	550	6.6	
18	50	50	230	6.9	
19	50	50	1700	5.7	
20	50	50	650	5.8	
21	50		60	7.1	
22	50		55	7.0	
23	55		60	6.9	
24	50		60	7.0	
25	50		300	6.4	
26	50		600	6.2	
27	50		270	6.6	
28	50		340	6.6	
29	50		980	6.1	
30	50		1800	6.0	71.3
29A	50		700	6.1	
31	50		600	6.2	
32	50		1800	6.0	
33	50		210	6.6	
34	50		340	6.7	
35	50		130	7.2	
C8	50		55	7.7	0.082

CONFEDERATION LAKE JULY 1992 TRANSECTS

Point #	X	Y	Z	milliS/cm	
BRC	220.0	95.0	0.0	1.9	
WH8	242.5	78.0	0.0	2.7	
M38	219.0	13.0	7.1	0.5	
BRP	160.0	133.0	0.0		
M18	152.5	119.5	8.7	0.9	
PRC	152.5	69.0	0.0	0.3	
BR13	116.0	93.0	0.0	1.6	
PRS	107.0	32.0	0.0	0.9	
36	88.0	28.5	1.5	0.1	0 m from shore S-N
37	88.5	36.5	1.3	0.1	0 m from shore S-N
38	87.0	44.0	1.8	0.1	0 m from shore S N
39	90.0	53.0	2.7	1.1	0 m from shore S-N
40	91.0	62.5	2.3	1.5	0 m from shore S-N
41	93.5	71.0	1.3	0.6	0 m from shore S-N
42	94.5	75.5	1.1	0.3	0 m from shore S-N
43	96.5	80.5	0.4	0.8	0 m from shore S-N
1	87.0	7.5	1.1	0.2	~5 m from shore S-N
2	87.5	15.0	1.8	0.1	~5 m from shore S-N
3	87.0	21.5	2.3	0.7	~5 m from shore S-N
4	85.0	27.5	2.7	0.8	~5 m from shore S-N
5	83.5	39.0	2.9	0.9	~5 m from shore S-N
6	85.0	47.5	2.9	1.3	~5 m from shore S-N
7	88.0	58.0	2.5	1.3	~5 m from shore S-N
8	89.0	67.0	2.0	0.4	~5 m from shore S-N
9	91.0	76.0	1.0	0.6	~5 m from shore S-N
10	92.0	84.0	0.5	0.1	~5 m from shore S-N
11	82.0	7.5	1.2	0.1	~10 m from shore S-N
12	83.5	15.0	1.9	0.1	~10 m from shore S-N
13	82.5	20.5	2.4	0.1	~10 m from shore S-N
14	81.0	27.0	2.8	0.2	~10 m from shore S-N
15	79.5	39.0	3.2	0.9	~10 m from shore S-N
16	81.0	48.5	3.2	0.9	~10 m from shore S-N
17	83.5	58.5	2.6	0.6	~10 m from shore S-N
18	84.5	67.5	3.2	0.2	~10 m from shore S-N
19	86.0	77.0	2.0	1.7	~10 m from shore S-N
20	86.5	85.0	2.0	0.7	~10 m from shore S-N
21	76.5	3.5	1.5	0.1	~25 m from shore S N
22	74.5	13.0	2.5	0.1	~25 m from shore S-N
23	72.5	20.5	3.4	0.1	~25 m from shore S-N
24	71.5	29.0	3.6	0.1	~25 m from shore S-N
25	71.5	39.5	4.1	0.3	~25 m from shore S-N
26	73.5	49.0	4.0	0.6	~25 m from shore S-N
27	76.0	60.0	3.5	0.3	~25 m from shore S-N
28	77.0	€8.0	3.6	0.3	~25 m from shore S-N
29	78.5	78.5	3.1	1.0	~25 m from shore S-N
30	79.5	85.0	2.1	1.8	~25 m from shore S-N
29A	66.0	79.0	3.2	0.7	E-W TRANSECT
31	71.0	86.5	2.3	0.6	E-W TRANSECT
32	64.5	87.0	3.5	1.8	E-W TRANSECT
33	54.5	87.5	4.2	0.2	E-W TRANSECT
34	42.5	87.5	4.2	0.3	E-W TRANSECT
35	30.5	87.5	4.3	0.1	E-W TRANSECT
C8	0	45.5	5	0.1	On lake

CONFEDERATION **LAKE** JULY 1992 TRANSECTS

Point#					
BRC	**330.0**	1082.68	12610	11527.3228	
WH8	**363.8**	1193.57	12720	**11526.4304**	
M38	328.5	1077.76	**12660**	11582.2441	
BRP	240.0	**787.40**	12400	**11612.5984**	
M18	228.8	750.66	12315	11564.3438	
PRC	228.8	750.66	12320	11569.3438	
BR13	174.0	570.87	12155	11584.1339	
PRS	160.5	526.57	12113	11586.4252	11569
36					
37	142.5	467.52	13781	**13313.4803**	
38	117	**383.86**	13700	13316.1417	
39	19.5	**63.98**	13380	13316.0236	
40	199.5	**654.53**	**13965**	13310.4724	
41	179.3	588.25	13900	13311.7454	
42	103.5	339.57	**13660**	13320.4331	
43	**139.5**	457.68	13795	13337.3228	
1	48	157.48	13495	13337.5197	13320
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
29A					
31					
32					
33					
34					
35					
C8					

07-Dec-92 **TABLE 2.**

SOUTHBAY SEEPAGES IN THE BACKFILL RAISE AREA

DATE	ASSAYERS#	LOCATION	pH	Cu	Zn	Fa	S

SOUTHBAY: SEEPAGES IN THE BACKFILL RAISE AREA

DATE	ASSAYERS#	LOCATION	pH	Cu	Zn	Fe	S
16-Jun-90	1807	CS13	5.4		1.05	0.08	7
16-Map91	2661	CS13	5.2	0.04	1.62		6.
25-Mar-92	3675	CS13	3.39		168	17	43
15-Jul-92	3886	CS13-6	5.73		62.7	4.25	23
14-Aug-92	4016	CS13-6	6.04	0.007	17.5		63.
15-Jul-92	3887	CS13-30	5.78		71.3	2.88	17
14-Aug-92	4019	CS13-30	5.78		142	20.6	35
25-Jun-91	2887	BR13	3	6.22	295	47.2	68
26-Jul-91	3w7	BR13	3.14		199	44	46
25-Sep-91	3450	BR13	3.72	4	221	23	49
13-Jul-92	3867	BR13	3.63		173	13.7	36
16-Jul-92	3876	BR13	5.54		84.2	4.31	16
14-Aug-92	4019	BR13	3.61	1.02	163	20.6	39
14-Maya9	1040	BR13C	5.6	5.9	881	9.3	125
14-Aug-92	4022	BR13C	4.97	0.405	78.2	4.24	21
14-Maya9	1024	BR18	3.28	10	249	56	65
25-Aug-89	1285	BR18	3.52	0.1	1.3	0.5	18
23-Jun-90	1790	BR18	4.2	0.7	128	29	38
16-May-91	2660	BR18	3.5	0.76	81	9.8	34
25-Jun-91	2868	BR18	3.22	0.78	96.2	8	28
26-Jul-91	3006	BR18	3.56		73	9	28
25-Sep-91	3449	BR18	3.7	1	138	42	42
14-Aug-92	4020	BR18	5.41	0.073	18.9	0.01 1	11
15-Jul-87	12	BRP	3	0.7	119	83	66
12-Aug-87	120	BRP	4.54	0.5	11	17	14
13-Jul-87	25	BR1A		0.5	14.8	107	25
12-Aug-87	117	BR1A	3.6	0.01	2.5	0.6	6
05-Oct-87	168	BR1A	3.35	0.5	19	9	12
11-Apr-88	304	BR1A		0.06	4.1	1	2
26-Jul-91	3005	BR1A	2.62	2	101	88	33
13-Jul-87	4	BR5		0.5			5
12-Aug-97	119	BR5		0.02		0.7	
05-Oct-87	175	BR5	5.87	0.1	7.2		11
20-Jun-88	471	BR4			0.7	0.1	1
14-Maya9	1035	BR4	3.02	1.4	20	72	16
26-Jul-91	3004	BR4	2.95		39	21	14
14-Jul-92	3874	BR4	3.86		6.94	2.91	49.
14-Aug-92	4023	BR4	3.14	0.356	16.8	52.2	15
05-Oct-87	169	BR3.5	6.34		0.4		2
13-Jul-87	17	BR3		0.5		3.5	4
12-Aug-87	118	BR3		0.01	0.1	0.1	2
16-May41	2656	BR3	3.1	0.24	96.9	30.3	22
13-Jul-87	8	BR2.5		0.2			
20-Jun-88	504	BR2.5		0.01	3.6	0.7	3
06-Nov-86		M11	6.7	0.1	22	70	60
02-Apr-87		M11	6.57	0.07	15	25.3	56
14-Jul-92	3878	WHS	3.24	9.29	919	38.5	107
14-Aug-92	4039	WHS	3.55	7.46	492	74.2	97
14-Jul-92	3873	BRC	5.61	1.85	642	19.5	83
13-Aug-92	4024	BRC	4.6	1.29	400	14.2	81
24-Mar-92	3678	MPC	4.67	4	383	84	63
13-Jul-92	3841	MPO	3.25	25.2	329	16.9	49
18-Jul-92	3848	MPO	3.65	14	233	18	39

07-Dec-92 TABLE 2.

SOUTHBAY: SEEPAGES IN THE BACKFILL RAISE AREA

DATE	ASSAYERS#	LOCATION	pH	Cu	Zn	Fe	S
13-Aug-92	4032	MPO	3.69	14.3	191	**36.8**	44
16-Jul-92	3861	TRO	2.96		116	53.5	**50**
18-Jul-92	3865	TRO	4.74	3.78	154	12.9	54
13-Aug-92	4033	TRO	2.4	**1.32**	213	**552**	111
13-Aug-92	**4034**	TRO	4.2	4.7	**209**	1.3	76
13-Jul-92	**3868**	PRS	5.62	1.5	46.2		15
16-Jul-92	3877	PRS	3.51	19.6	122	3.74	17
14-Aug-92	4038	PRS	5.64	0.578	22.2	**0.201**	99.
06-Nov-86		M18	6.7	**0.05**	7.4	**88**	32
02-Apr-87		M16	6.6	0.02	4.8	25	39
12-Apr-88	330	**M18**	5.8	0.1	19	**54**	**34**
25-Mar-92	3657	**M18**	8.52		10		21
14-Jul-92	3870	M18	7.13		12.3		21
14-Aug-92	4026	M18	6.6	0.007	8.91		22
06-Nov-86		M38	6.5	0.06	**55**	6.3	12
02-Apr-87		M38	6.25	0.01	**77**	14.5	17
01Jun-87		M38	6.03	0.07	70		17
12-Apr-88		M38	6.07	**0.03**	41	2.2	15
14-Oct-89	1478	M38	5.55	**0.06**	**30**	0.1	8
25-Mar-92	3672	**M38**	6.07		19	2	8
14-Jul-92	3871	**M38**	6.31		15.6		**80.**
14-Aug-92	**4036**	**M38**	6.13	0.017	12.7	**0.035**	75.
14-Jul-92	3875	PRC	7.81		1.24		24.
14-Aug-92	**4037**	PRC	6.26	**0.038**	2.95	0.245	41.
14-Aug-92	**4021**	BR13B	6.51	0.024	3.19	**0.035**	11.
13-Aug-92	4030	CAT2	7.5	**0.005**	**0.054**	0.071	2.6

SOUTHBAY SEEPAGES IN THE BACKFILL RAISE AREA

DATE	ASSAYERS#	LOCATION	Ca	Mg	
SOUTHBAY SEEPAGES IN THE BACKFILL RAISE AREA					
DATE	ASSAYERS#	LOCATION	Ca	Mg	
16-Jun-90	1807	CS13			
16-May-91	2661	CS13			
25-Mar-92	3675	CS13	302	65	CS13
15-Jul-92	3886	CS13-6	196	32.4	CS13-6
14-Aug-92	4016	CS13-6	61.7	10.5	
15-Jul-92	3887	CS13-30	129	23.8	
14-Aug-92	4016	CS13-30	275	46	CS13-30
25-Jun-91	2867	BR13			BR13
26-Jul-91	3007	BR13			
25Sep-91	3450	BR13			
13-Jul-92	3867	BR13	221	47.7	
16-Jul-92	3876	BR13	118	26.7	
14-Aug-92	4019	BR13	240	53.5	
14-May43	1040	BR13C			BR13C
14-Aug-92	4022	BR13C	158	32	
14-May#	1M4	BR18			BR18
25-Aug-89	1285	BR18			
23-Jun-90	1790	BR18			
16-May-91	2660	BR18			
25Jun-91	2868	BR18			
26-Jul-91	3006	BR18			
25-Sep-91	3449	BR18			
14-Aug-92	4020	BR18	99.7	16.2	
15-Jul-87	12	BRP			BRP
12-Aug-87	120	BRP			
13-Jul-87	25	BR1A			
12-Aug-87	117	BR1A			
05-Oct-87	168	BR1A			
11-Apr-88	304	BR1A			
26-Jul-91	3005	BR1A			BR1A
13-Jul-87	4	BR5			
12-Aug-87	119	BR5			
05-Oct-87	175	BR5			BR5
20-Jun-88	471	BR4			
14-May#	1035	BR4			BR4
26-Jul-91	3004	BR4			
14-Jul-92	3874	BR4	29.5	6.84	
14-Aug-92	4023	BR4	47.3	15.1	
05-Oct-87	169	BR3.5			BR3.5
13Jul-87	17	BR3			
12-Aug-87	116	BR3			
16-May91	2656	BR3			BR3
13-Jul-87	8	BR2.5			
20-Jun-88	504	BR2.5			BR2.5
06-Nov-86		M11	683	61	M11
02-Apr-87		M11	728	79	
14Jul-92	3878	WHS	513	153	WHS
14-Aug-92	4039	WHS	483	132	
14-Jul-92	3873	BRC	476	129	BRC
13-Aug-92	4024	BRC	474	111	
24-Mar-92	3678	MPC	373	79	MP
13-Jul-92	3841	MPO	278	51.4	
18-Jul-92	3848	MPO	236	42	

SOUTHBAY: SEEPAGES IN THE BACKFILL RAISE AREA

DATE	ASSAYERS#	LOCATION	Ca	Mg	
13-Aug-92	4032	MPO	304	49.7	
16-Jul-92	3861	TRO	303	58.6	
18-Jul-92	3865	TRO	461	79.3	
13-Aug-92	4033	TRO	318	107	TRO
13-Aug-92	4034	TRO	564	95.9	
13-Jul-92	3868	PRS	126	20.9	
16-Jul-92	3877	PRS	93.5	15.6	PRS
14-Aug-92	4038	PRS	90.7	14.6	
06-Nov-86		M18	372	56	
02-Apr-87		M18	539	74	M18
12-Apr-88	330	M18	276	48	
25-Mar-92	3657	M18	257	38	
14-Jul-92	3870	M16	240	36.3	
14-Aug-92	4026	M18	278	39.4	
06-Nov-86		M38	134	13	
02-Apr-87		M38	191	19	M38
01Jun-97		M38	154	16	
12-Apr-88		M38	144	16	
14-Oct-89	1478	M38	105	11	
25-Mar-92	3672	M38	128	15	
14-Jul-92	3871	M38	119	15.1	
14-Aug-92	4036	M38	117	15.1	
14-Jul-92	3875	PRC	62.7	5.63	
14-Aug-92	4037	PRC	86	9.72	PRC
14-Aug-92	4021	BR13B	61.1	12.6	BR13B
13-Aug-92	4030	CAT2	13.9	1.91	

07-Dec-92

TABLE 2.

SORTED FOR ZINC SEEPAGES IN THE BACKFILL RAISE AREA

DATE	ASSAYERS#	LOCATION	pH	Cu	Zn	Fe	S

SORTED FOR ZINC SEEPAGES IN THE BACKFILL RAISE AREA

DATE	ASSAYERS#	LOCATION	pH	Cu	Zn	Fe	S
12-Aug-87	119	BR5		0.02		0.7	
13-Jul-87	8	BR2.5		0.2			
13-Jul-87	17	BR3		0.5		3.5	4
13-Jul-87	4	BR5		0.5			5
13-Aug-92	4030	CAT2	7.5	0.005	0.054	0.071	2.6
12-Aug-87	116	BR3		0.01	0.1	0.1	2
05-Oct-87	169	BR3.5	6.34		0.4		2
20-Jun-88	471	BR4			0.7	0.1	1
16-Jun-90	1807	CS13	5.4		1.05	0.08	7
14-Jul-92	3875	PRC	7.81		1.24		24.
25-Aug-89	1285	BR18	3.52	0.1	1.3	0.5	18
16-May91	2661	CS13	5.2	0.04	1.62		6.
12-Aug-87	117	BRIA	3.6	0.01	2.5	0.6	6
14-Aug-92	4037	PRC	6.28	0.038	2.95	0.245	41.
14-Aug-92	4021	BR13B	6.51	0.024	3.19	0.035	11.
20-Jun-88	504	BR2.5		0.01	3.6	0.7	3
11-Apr-88	304	BRIA		0.06	4.1	1	2
02-Apr-87		M18	6.6	0.02	4.8	25	39
14-Jul-92	3874	BR4	3.86		6.94	2.91	49.
05-Oct-87	175	BR5	5.87	0.1	7.2		11
06-Nov-86		M18	6.7	0.05	7.4	88	32
14-Aug-92	4026	M18	6.6	0.007	8.91		22
25-Mar42	3657	M18	6.52		10		21
12-Aug-87	120	BRP	4.54	0.5	11	17	14
14-Jul-92	3870	M18	7.13		12.3		21
14-Aug-92	4036	M38	6.13	0.017	12.7	0.035	75.
13-Jul-87	25	BR1A		0.5	14.8	107	25
02-Apr-87		M11	6.57	0.07	15	25.3	58
14-Jul-92	3871	M38	6.31		15.8		80.
14-Aug-92	4016	CS13-6	6.04	0.007	17.5		63.
05-Oct-87	168	BRIA	3.35	0.5	18	9	12
14-Aug-92	4023	BR4	3.14	0.356	18.8	52.2	15
14-Aug-92	4020	BR18	5.41	0.073	18.9	0.011	11
25-Mar-92	3672	M38	6.07		19	2	8
12-Apr-88		M18	5.8	0.1	19	54	34
14-May49	1035	BR4	3.02	1.4	20	72	16
06-Nov-86		M11	6.7	0.1	22	70	60
14-Aug-92	4038	PRS	5.64	0.578	22.2	0.201	99.
14-Oct-89		M38			30	0.1	8
26-Jul-91	3004	BR4	2.95		39	21	14
12-Apr-88		M38	6.07	0.03	41	2.2	15
13-Jul-92	3868	PRS	5.62	1.5	46.2		15
06-Nov-86		M38	6.5	0.06	*55*	6.3	12
15-Jul-92	3886	CS13-6	5.73		62.7	4.25	23
01-Jun-87		M38	6.03	0.07	70		17
15-Jul-92	3887	CS13-30	5.78		71.3	2.88	17
26-Jul-91	3006	BR18	3.56		73	9	28
02-Apr-87		M38	6.25	0.01	77	14.5	17
14-Aug-92	4022	BR13C	4.97	0.405	78.2	4.24	21
16-May41	2660	BR18	3.5	0.76	81	9.6	34
16-Jul-92	3876	BR13	5.54		84.2	4.31	18
25-Jun-91	2868	BR18	3.22	0.78	96.2	8	28
16-May91	2656	BR3	3.1	0.24	96.9	30.3	22

07-Dec-92

TABLE 2.

SORTED FOR ZINC SEEPAGES IN THE BACKFILL RAISE ARE4

DATE	ASSAYERS#	LOCATION	pH	Cu	Zn	Fe	S
26-Jul-91	3005	BR1A	2.62	2	101	88	33
16-Jul-92	3861	TRO	2.96		116	53.5	50
15-Jul-87	12	BRP	3	0.7	119	63	68
16-Jul-92	3677	PRS	3.51	19.6	122	3.74	17
23-Jun-90	1790	BR18	4.2	0.7	128	29	38
25-Sep-91	3449	BR18	3.7	1	138	42	42
14-Aug-92	4016	CS13-30	5.78		142	20.6	35
18-Jul-92	3865	TRO	4.74	3.78	154	12.9	54
14-Aug-92	4019	BR13	3.61	1.02	163	20.6	39
25-Mar-92	3675	CS13	3.39		168	17	43
13-Jul-92	3867	BR13	3.63		173	13.7	36
13-Aug-92	4032	MPO	3.69	14.3	191	36.8	44
26-Jul-91	3007	BR13	3.14		199	44	46
13-Aug-92	4034	TRO	4.2	4.7	209	13	76
13-Aug-92	4033	TRO	2.4	1.32	213	552	111
25-Sep-91	3450	BR13	3.72	4	221	23	49
18-Jul-92	3848	MPO	3.65	14	233	18	39
14-May-89	1024	BR18	3.28	10	249	58	65
25-Jun-91	2667	BR13	3	6.22	295	47.2	68
13-Jul-92	3841	MPO	3.25	25.2	329	18.9	49
24-Mar—	3678	MPC	4.67	4	383	84	63
13-Aug-92	4024	BRC	4.8	1.29	400	14.2	81
14-Aug-92	4039	WHS	3.55	7.46	492	74.2	97
14-Jul-92	3873	BRC	5.61	1.85	642	19.5	83
14-May-89	1040	BR13C	5.8	5.9	681	9.3	125
14-Jul-92	3676	WHS	3.24	9.29	919	36.5	107

07-Dec-92 TABLE 2.

SORTED FOR ZINC SEEPAGES IN THE BACKFILL RAISE AREA

DATE	ASSAYERS#	LOCATION	Fe/S	Zn/S	Fe/Zn	
SORTED FOR ZINC		SEEPAGES IN THE BACKFILL RAISE AREA				
DATE	ASSAYERS#	LOCATION	Fe/S	Zn/S	Fe/Zn	
12-Aug-87	119	BR5	3.93%	21.00%	8.02%	BR13
13-Jul-87	8	BR2.5	5.47%	21.12%	11.15%	BR13
13-Jul-87	17	BR3	2.66%	21.85%	5.43%	BR13
13-Jul-87	4	BR5	2.16%	23.31%	4.41%	BR13
13-Aug-92	4030	CAT2	1.46%	24.43%	2.99%	BR13
12-Aug-87	118	BR3	2.99%	20.16%	6.09%	BR13
05-Oct-87	169	BR3.5				
20-Jun-88	471	BR4	0.42%	34.34%	0.87%	BR13C
16-Jun-90	1807	CS13	1.13%	17.75%	2.30%	BR13C
14-Jul-92	3875	PRC	0.17%	13.49%	0.35%	BR13B
25-Aug-89	1285	BR18				
16-May91	2661	CS13	5.10%	18.70%	10.40%	BR18
12-Aug-87	117	BR1A	0.15%	0.34%	0.31%	BR18
14-Aug-92	4037	PRC	4.38%	16.52%	8.93%	BR18
14-Aug-92	4021	BR13B	1.63%	11.48%	3.32%	BR18
20-Jun-88	504	BR2.5	1.64%	16.85%	3.34%	BR18
11-Apr-88	304	BRIA	1.83%	12.65%	3.72%	BR18
02-Apr-87		M18	5.73%	16.07%	11.68%	BR18
14-Jul-92	3874	BR4	0.01%	8.13%	0.01%	BR18
05-Oct-87	175	BR5				
06-Nova		M18	15.45%	1.11%	31.51%	M18
14-Aug-92	4026	M18	3.68%	0.60%	7.50%	M18
25-Mar-92	3657	M18	8.93%	2.68%	18.22%	M18
12-Aug-87	120	BRP	0.00%	2.29%	0.00%	M18
14-Jul-92	3870	M18	0.00%	2.81%	0.00%	M16
14-Aug-92	4036	M38	0.00%	1.92%	0.00%	M18
13-Jul-87	25	BRIA				
02-Apr-87		M11	24.38%	2.88%	49.71%	BR1A
14-Jul-92	3871	M38	0.52%	1.86%	1.06%	BR1A
14-Aug-92	4016	CS13-6	4.07%	6.95%	8.30%	BRIA
05-Oct-87	168	BRIA	2.50%	8.74%	5.09%	BR1A
14-Aug-92	4023	BR4	15.13%	14.83%	30.84%	BRIA
14-Aug-92	4020	BR18				
25-Mar-92	3672	M38	0.00%	0.00%	0.00%	BR5
12-Apr-88		M18				BR5
14-May-89	1035	BR4	0.00%	3.12%	0.00%	BR5
06-Nov-86		M11				
14-Aug-92	4038	PRS	0.41%	2.45%	0.84%	BR4
14-Oct-89		M38	24.46%	5.80%	49.88%	BR4
26-Jul-91	3004	BR4	8.31%	13.19%	16.95%	BR4
12-Apr-88		M38	3.39%	6.90%	6.91%	BR4
13-Jul-92	3868	PRS	18.97%	5.83%	38.68%	BR4
06-Nov-86		M38				
15-Jul-92	3886	CS13-6	0.00%	0.73%	0.00%	BR3.5
01-Jun-87		M38	4.67%	0.00%	9.53%	BR3
15-Jul-92	3887	CS13-30	0.20%	0.17%	0.40%	BR3
26-Jul-91	3006	BR18	7.80%	21.31%	15.91%	BR3
02-Apr-87		M38				
14-Aug-92	4022	BR13C	0.00%	0.00%	0.00%	BR2.5
16-May41	2660	BR18	1.12%	4.90%	2.28%	BR2.5
16-Jul-92	3876	BR13				
25-Jun-91	2868	BR18	6.61%	1.77%	13.48%	M11
16-May41	2656	BR3	2.48%	1.26%	5.06%	M11

07-Dec-92 **TABLE *2.***

SORTED FOR ZINC SEEPAGES IN THE BACKFILL RAISE AREA

DATE	ASSAYERS#	LOCATION	Fe/S	Zn/S	Fe/Zn	
26-Jul-91	3005	BR1A				
16-Jul-92	3861	TRO	**0.00%**	**0.00%**	**0.00%**	WHS
15-Jul-87	12	BRP	**1.12%**	**4.90%**	2.26%	WHS
16-Jul-92	**3877**	PRS				
23-Jun-90	1790	BR18	6.61%	1.77%		
25-Sep-91	**3449**	BR18	2.46%	**1.26%**		
14-Aug-92	4018	CS13-30				
18-Jul-92	**3865**	TRO	1.64%	16.85%		
14-Aug-92	4019	BR13	**1.83%**	**12.65%**	**13.48%**	BRC
25-Mar-92	3675	CS13			5.06%	BRC
13-Jul-92	3867	BR13	**0.06%**	**16.53%**		
13-Aug-92	**4032**	MPO	1.34%	10.63%	3.34%	BRP
26-Jul-91	3007	BR13			**3.72%**	BRP
13-Aug-92	**4034**	**TRO**	**6.09%**	**11.29%**		
13-Aug-92	**4033**	**TRO**	**1.36%**	13.91%	0.13%	PRC
25-Sep-91	**3450**	BR13	28.55%	9.41%	2.72%	PRC
18-Jul-92	**3848**	MPO				
14-May-89	1024	BR18	ERR	ERR	12.43%	PRS
25-Jun-91	2867	BR13	ERR	ERR	2.76%	**PRS**
13-Jul-92	**3841**	MPO			**58.22%**	PRS
24-Mar-92	3678	MPC				
13-Aug-92	4024	BRC	**0.06%**	0.71%	**0.00%**	PRS
14-Aug-92	4039	WHS	**0.00%**	12.22%	2.50%	PRS
14-Jul-92	3673	BRC			0.24%	PRS
14-Maya	1040	BR13C				
14-Jul-92	3878	WHS			0.13%	CS13

SOUTHBAY: SEEPAGES **IN THE** BACKFILL RAISE ARE4

DATE	ASSAYERS#	LOCATION	pH	Cu	Zn	Fe	S
DATE	ASSAYERS#	LOCATION	pH	Cu	Zn	Fe	S
25-Mar-92	3675	CS13	3.39		168	17	43
15-Jul-92	3886	CS13-6	5.73		62.7	4.25	23
14-Aug-92	4016	CS13.6	6.04	0.007	17.5		63.
15-Jul-92	3887	CS13-30	5.78		71.3	2.86	17
14-Aug-92	4018	CS13-30	5.78		142	20.6	35
13-Jul-92	3867	BR13	3.63		173	13.7	38
16-Jul-92	3876	BR13	5.54		84.2	4.31	16
14-Aug-92	4019	BR13	3.61	1.02	163	20.6	39
14-Aug-92	4022	BR13C	4.97	0.405	78.2	4.24	21
14-Aug-92	4020	BR18	5.41	0.073	18.9	0.01 1	11
14-Jul-92	3874	BR4	3.86		6.94	2.91	49.
14-Aug-92	4023	BR4	3.14	0.356	18.8	52.2	15
14-Jul-92	3678	WHS	3.24	8.29	919	38.5	107
14-Aug-92	4039	WHS	3.55	7.46	492	74.2	97
14-Jul-92	3873	BRC	5.61	1.85	642	19.5	83
13-Aug-92	4024	BRC	4.8	1.29	400	14.2	81
24-Mar-92	3678	MPC	4.67	4	383	84	63
13-Jul-92	3841	MPO	3.25	25.2	329	18.9	49
18-Jul-92	3848	MPO	3.65	14	233	18	39
13-Aug-92	4032	MPO	3.69	14.3	191	36.8	44
16-Jul-92	3861	TRO	2.96		116	53.5	50
18-Jul-92	3865	TRO	4.74	3.78	154	12.9	54
13-Aug-92	4033	TRO	2.4	1.32	213	552	111
13-Aug-92	4034	TRO	4.2	4.7	209	13	76
13-Jul-92	3868	PRS	5.62	1.5	46.2		15
16-Jul-92	3877	PRS	3.51	19.6	122	3.74	17
14-Aug-92	4038	PRS	5.64	0.578	22.2	0.201	99.
06-Nov-86		M11	6.7	0.1	22	70	60
02-Apr-87		M11	6.57	0.07	15	25.3	58
25-Mar-92	3657	M18	6.52		10		21
14-Jul-92	3870	M18	7.13		12.3		21
14-Aug-92	4026	M18	6.6	0.007	8.91		22
25-Mar-92	3672	M38	6.07		19	2	8
14-Jul-92	3871	M38	6.31		15.8		80.
14-Aug-92	4036	M38	6.13	0.017	12.7	0.035	75.
14-Jul-92	3875	PRC	7.81		1.24		24.
14-Aug-92	4037	PRC	6.28	0.038	2.95	0.245	41.

07-Dec-92

TABLE 2.

SOUTHBAY: SEEPAGES IN THE BACKFILL RAISE ARE4

DATE	ASSAYERS#	LOCATION	pH	CU	Zn	Fe	S
14-Aug-92	4021	BR13B	6.51	0.024	3.19	0.035	11.
13-Aug-92	4030	CAT2	7.5	0.005	0.054	0.071	2.6

DATE

SOUTHBAY: SEEPAGES IN THE BACKFILL RAISE AREA

DATE	ASSAYER	SX	LOCATION	Ca	Mg	
25-Mar@		3675	CS13	302	65	CS13
15-Jul-92		3886	CS13-6	196	32.4	
14-Aug-92		4016	CS13-6	61.7	10.5	
15-Jul-92		3887	CS13-30	129	23.6	
14-Aug-92		4018	CS13-30	275	46	CS13-30
13-Jul-92		3867	BR13	221	47.7	
16-Jul-92		3676	BR13	118	26.7	
14-Aug-92		4019	BR13	240	53.5	BR13
14-Aug-92		4022	BR13C	158	32	BR13C
14-Aug-92		4020	BR18	99.7	16.2	BR18
14-Jul-92		3674	BR4	29.5	6.84	
14-Aug-92		4023	BR4	47.3	15.1	BR4
14-Jul-92		3678	WHS	513	153	WHS
14-Aug-92		4039	WHS	483	132	
14-Jul-92		3673	BRC	476	129	BRC
13-Aug-92		4024	BRC	474	111	
24-Mar-92		3676	MPC	373	79	MP
13-Jul-92		3841	MPO	278	51.4	
18-Jul-92		3848	MPO	236	42	
13-Aug-92		4032	MPO	304	49.7	
16-Jul-92		3861	TRO	303	58.6	
18-Jul-92		3865	TRO	461	79.3	
13-Aug-92		4033	TRO	318	107	TRO
13-Aug-92		4034	TRO	564	95.9	
13-Jul-92		3868	PRS	126	20.9	
16-Jul-92		3677	PRS	93.5	15.6	PRS
14-Aug-92		4038	PRS	90.7	14.6	
06-Nov-86			M11	683	61	M11
02-Apr-87			M11	726	79	
25-Mar-92		3657	M18	257	38	
14-Jul-92		3870	M18	240	36.3	
14-Aug-92		4026	M18	276	39.4	M18
25-Mar@		3672	M38	128	15	M38
14-Jul-92		3671	M38	119	15.1	
14-Aug-92		4036	M38	117	15.1	
14-Jul-92		3675	PRC	62.7	5.63	
14-Aug-92		4037	PRC	86	9.72	PRC
14-Aug-92		4021	BR13B	61.1	12.8	BR13B
13-Aug-92		4030	CAT2	13.9	1.91	CAT2

07-Dec-92

TABLE 3

WATERLEVEL ELEVATIONS. m

LOCATION	SOURCE	SOURCE	Coordinates(ft) Northing	Coordinates(ft) Easting	Stick-up m	Elevations. m Collar	Elevations. m Screen Top	Elevations. m Screen Bottom
M13	PIEZOMETER	PIEZOMETER	13595	13740	0.17	427.38	426.29	413.28
MP	MILL POND	MIUPOND	13180	13600				
M57	PIEMMETER	PIEMMETER	13430	13800	0.73	422.63	412.87	412.87
M38	PIEMMETER	PIEMMETER	13380	12660	0.53	423.53	417.39	418.48
Mil *	PIEZOMETER	PIEZOMETER	13580	13035	0.18	423.61	418.63	415.72
WHS	WH SEEP	WH SEEP	13700	12720				
M14	PIEZOMETER	PIEZOMETER	13140	13655	0.30	418.24	414.80	413.28
BRP	SFR POND	BFR FOND	13965	12400				
Mi8	PIEMMETER	PIEMMETER	13900	12315	0.71	417.13	409.41	408.16
PRC	PR CAP	PR *CAP*	13680	12320				
BRC	BFR CAP	SFR CAP	13781	12810				
BR13	FUND	FUND	13795	12155				
PRS	NORM SEEP	NORTH SEEP	13515	12118				
C30	SEEP in LK	SEEP in LK	13738	12000				
C6	SEEP in LK	SEEP in LK	13554	12000				

07-Dec-92

TABLE 3

LOCATION	SOURCE	Collar to Tip m
M13	PIEZOMETER	1410
MP	MILL POND	
M57	PIEZOMETER	9.99
M38	PIEZOMETER	7.11
M11 *	PIEZOMETER	7.95
WHS	WH SEEP	
M14	PIEZOMETER	4.96
BRP	BFR WND	
M18	PIEZOMETER	8.97
PRC	PR CAP	
BRC	BFR CAP	
BR13	POND	
PRS	NORM SEEP	
C30	SEEP in LK	
C6	SEEP in LK	

07-Dec-92

TABLE 3

WATERLEVELS, m

LOCATION	1 —88 31700	05-Nov-86 31721	22-Nov-86 31738	30-Nov-86 31748	07 —88 31753	14-Dec-86 31760	21-Dec-86 31787
M13	424.37	423.25	423.00	422.90	422.64	422.78	422.70
MP							
M57		418.48					
M38	421.35	420.77					
M11 *	421.78	421.60					
WHS							
M14	418.08	418.08					
BRP							
M18	414.71	414.41					
PRC							
BRC							
BR13							
PRS							
C30							
C6							

07-Dec-92

TABLE 3

WATERLEVELS, m

LOCATION	28-Dec-86 31774	04-Jan-87 31781	11-Jan-87 31788	25-Jan-87 31802	08-Feb-87 31818	15-Feb-87 31823	21-Feb-87 31829
M13	422.65	422.58	422.58	422.30	422.07	422.01	421.94
MP							
M57							
M38		418.88	418.81	418.54	418.25	418.14	419.03
M11 *		421.23	421.21	420.99	420.79	420.76	420.71
WHS							
M14							
BRP							
M18		413.94	413.82	413.77	413.64	413.60	413.58
PRC							
BRC							
BR13							
PRS							
C30							
C6							

07-Dec-92

TABLE 3

LOCATION	WATERLEVELS, m							
	01-Mar-87 31837	15-Mar-87 31851	29-Mar-87 31865	15-Apr-87 31882	29-Apr-87 31896	06-May-87 31903	14-May-87 31911	23-May-87 31920
M13	421.88	421.69	423.83	423.83	423.94	423.62	423.32	423.42
MP								
M57			421.50	421.83	421.W	421.35	421.17	421.37
M38	418.93	418.74	419.08	421.47	421.39	421.23	421.01	420.96
M11 *	420.66	420.63	420.93	421.72	420.73	420.71	420.67	420.71
WHS								
M14			417.71	417.78	417.71	417.74	417.74	417.74
BRP								
M18	418.51	413.48	413.78	414.01	41453	414.63	414.48	414.40
PRC								
BRC								
BR13								
PRS								
C30								
C6								

07-Dec-92

TABLE 3

WATERLEVELS, m

LOCATION	03-Jun-87 31831	11-Jun-87 31939	20-Jun-87 31948	28-Jun-87 31956	05-Jul-87 31963	16-Jul-87 31978	15-Aug-87 32004	25-Sep-87 32045
M i3	423.87	423.58	423.44	423.08	422.93	423.08	422.68	422.40
MP								
M57	421.58	421.35	421.14	420.90	420.79	420.89	420.84	420.53
M38	420.96	420.98	420.83	420.63	420.50	420.32	418.83	419.27
M11 *	420.75	420.78	420.72	420.66	420.65	420.61	420.51	420.21
WHS								
M14	417.74	417.74	417.74	417.74	417.74	417.73	417.80	417.44
BRP								
M18	414.33	414.35	414.30	414.18	414.13	413.88	413.83	413.87
PRC								
BRC								
BR13								
PRS								
C30								
C6								

07-Dec-92

TABLE 3

LOCATION	06-Oct-87 32056	12-Nov-87 32093	14-Dec-87 32125	17-Jan-88 32159	08-Apr-88 32241	25-Apr-88 32258	16-Jun-88 32310	23-Aug-88 32378
M13	422.26	422.57	422.15	421.68	423.73	423.89	423.18	422.96
MP								
M57	420.50	420.75	420.83	420.24	420.27			420.76
M38	419.05	418.77	418.81	418.13	417.53	419.13	420.37	419.46
M11 *								
WHS								
M14	417.44	417.39	417.28	416.89	417.88	418.09	417.75	417.86
BRP								
M18	413.51	413.36	413.15	412.92	412.99	414.18	413.94	414.26
PRC								
BRC								
BR13								
PRS								
C30								
C6								

07-Dec-92

TABLE 3

LOCATION	WATERLEVELS, m						
	22-Jul-89 32711	26-Aug-89 32746	09-Sep-89 32760	23-Sep-89 32774	07-Oct-89 32788	15-Oct-89 32796	17-Nov-89 32829
M13	423.32	423.24	423.69	423.92	423.43	423.26	422.69
MP							
M57	421.12	421.16	421.85	421.57	421.28	421.13	420.94
M38	421.01	420.81	421.13	421.12	420.91	420.80	420.55
M11 *							
WHS							
M14	418.24	418.M	418.24	418.M	418.02	418.W	417.05
BRP							
M18	415.74	414.88	415.32	414.99	41475	41487	414.48
PRC							
BRC							
BR13							
PRS							
C30							
C6							

07-Dec-92

TABLE 3

LOCATION	WATERLEVELS, m							
	04-Dec-89 32846	27-Mar-90 32959	20-Apr-90 32983	03-May-90 32996	12-May-90 33005	16-Jun-90 33040	14-Jul-90 33068	19-Aug-90 33104
M13	422.67	422.66	425.14	425.12	424.84	424.80		
MP								
M57	420.91	420.93	420.91	420.83	421.61	421.76	421.88	420.69
M38	420.54	420.13	422.16	422.14	422.04	422.00	421.30	420.70
M11 *								
WHS								
M14	417.82	417.80	417.04	417.88	418.24	418.03	418.04	417.88
BRP								
M18	414.45	414.43	415.48	415.41	415.40	415.38	415.07	414.88
PRC								
BRC								
BR13								
PRS								
C30								
C6								

07-Dec-92

TABLE 3

WATERLEVELS, m

LOCATION	04-Dec-89 32846	27-Mar-90 32959	20-Apr-90 32983	03-May-90 32996	12-May-90 33005	16-Jun-90 33040	14-Jul-90 33068	19-Aug-90 33104
M13	422.87	422.86	425.14	425.12	424.84	424.80		
MP								
M57	420.91	420.93	420.91	420.83	421.81	421.76	421.69	420.89
M38	420.54	420.13	422.18	422.14	422.04	422.00	421.30	420.70
M11 *								
WHS								
M14	417.92	417.90	417.94	417.86	418.24	418.03	418.04	417.98
BRP								
M18	414.45	414.43	415.49	415.41	415.40	415.36	415.07	414.69
PRC								
BRC								
BR13								
PRS								
C30								
C6								

07-Dec-92

TABLE 3

A - WATERLEVELS,

LOCATION	12-Oct-90 33158	14-Oct-90 33160	25-Oct-90 33171	18-Nov-90 33195	15-Dec-90 33222	26-Feb-91 33295	24-Mar-92 33687
M13							
MP							
M57		421.60	421.29	420.92	420.91	420.63	420.9
M38		420.71	420.60	420.37	420.36	420.31	420.14
M11 *							
WHS							
M14		417.96	417.93	417.78	417.75	417.62	
BRP							
M18			414.62	414.46	414.45	414.37	414.38
PRC							
BRC							
BR13							
PRS							
C30							
C6							

* M11 average waterl

07-Dec-92

TABLE 3

LOCATION	12-Jul-92 33797	13-Aug-92 33829	16-Oct-92 33893	'86-'92 MIN	'86-'92 MAX
M13	423.88		423.5	421.88	425.14
MP	421.82			421.82	421.82
M57	421.53		421.31	418.48	421.85
M38	421.35	421.10	421.13	417.53	422.18
M11 *	421.0 *			420.21	421.78
WHS	418.18			418.18	418.18
M14	418.00			418.88	418.24
BRP	415.88			415.88	415.88
M18	415.14	415.11	415.14	41282	415.74
PRC	414.83	414.81	414.84	414.81	414.83
BRC	414.82	41483	414.07	414.82	414.83
BR13	413.54			413.54	413.54
PRS	413.04			413.04	413.04
C30	409.75	409.75		409.75	409.75
C6	408.95	408.95		408.95	408.95

07-Dec-92

TABLE 3

LOCATION	SOURCE	LOCATION	SOURCE	Zn	
M13	PIEZOMETER	M13	PIEMMETER	13595	13740
MP	MILL FUND	MP	MILL POND	13180	13600
M57	PIEZOMETER	M57	PIEMMETER	13430	13800
M38	PIEZOMETER	M38	PIEMMETER	13380	12660
M11 **	PIEZOMETER	M11 **	PIEMMETER	13590	13035
WHS	WH SEEP	WHS	WH SEEP	13700	12720
M14	PIEZOMETER	M14	PIEMMETER	13140	13655
BRP	BFR POND	BRP	BFR FUND	13965	12400
M18	PIEZOMETER	M18	PIEMMETER	13900	12315
PRC	PRCAP	PRC	PR CAP	13660	12320
BRC	BFR CAP	BRC	BFR CAP	13781	12610
BR18	POND	BR18	POND	13870	12260
BR13	FUND	BR13	FUND	13785	12155
PRS	NORTH SEEP	PRS	NORTH SEEP	13515	12118
C30	SEEP in LK	C30	SEEP in LK	13738	12000
C6	SEEP in LK	C6	SEEP in LK	13554	12000

07-Dec-92

TABLE 3

LOCATION	33688	33797	33801	33829		
M13		0.814				
MP	383	329	233	191		
M57	9	8.58				
M38	19	15.6		12.7		
M11 **		15 **				
WHS		919		492		
M14		186				
BRP						
M18	10	12.3		9.21		
PRC		1.24		2.95		
BRC		642		400		
BR18				16.9		
BR13		173	84.2	163		
PRS		46.2	122	22.2		
C30	166	71.3		142		
C6		62.7		17.5		

ation, 4 April 1987

SOUTHBAY: DATA SOURCES for 1992 samples
used in WATEQ4F and NETPATH

#	T	pH	Eh	Alk. (TIC)
JULY '92 SAMPLES				
WHS	(16)	L	L	(2)
BRC	(15)	L	(320)	L
MP	F	F	F	(2)
BR13	F	F	F	L
C13-30	F	F	F	(2)
PRS	F	F	F	L
PRC	(16)	L	(320)	L
AUGUST '92 SAMPLES				
WHS	L	L	L	(2)
BRC	F	F	L	(2)
MP	L	L	L	(2)
BR13	L	L	L	(2)
C13-30	F	F	L	(2)
PRS	L	L	L	(2)
PRC	L	L	L	L
GRPIT	F	F	L	L

F=field data; L=lab.data.
(16)=value added for use in WATEQ4F.
No chloride data were available.

CHEMISTRY OF PRECIPITATION- EAR FALLS, ONT.

YEAR	YEAR	Monthly Precip.	Ca mg/m^2	Mg mg/m^2	K mg/m^2	Na mg/m^2	Mn mg/m^2	Ni mg/m^2	Zn mg/m^2	Fe mg/m^2
1981	1981	32.4	6.781	1.394	2.215	1.741	0.2859	0.0514	0.38	1.692
1982	1982	32.9	7.516	1.286	2.837	2.498	0.2192	0.0397	0.3	2.4247
1983	1983	32.7	4.487	1.342	1.65	1.402	0.0888	0.0232	0.16	2.2038
		32.7	6.262	1.341	2.234	1.880	0.198	0.038	0.280	2.107
		m^3/m^2	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
		0.03266667	0.19169388	0.04104082	0.06838776	0.05756122	0.0060602	0.00116633	0.00857143	0.0644949
			40.08	24.305	39.098	22.98977	55	58.71	65.38	55.647
			Ca mmole/L	Mg mmole/L	K mmole/L	Na mmole/L	Mn mmole/L	Ni mmole/L	Zn mmole/L	Fe mmole/L
			4.78E-03	1.69E-03	1.75E-03	2.50E-03	1.10E-04	1.99E-05	1.31E-04	1.15E-03

CHEMISTRY OF PRECIPITATION- EAR FALLS, ONT.

YEAR	Monthly Precip.	Pb mg/m^2	V mg/m^2	Al mg/m^2	cu mg/m^2	Cd mg/m^2
1981	32.4	0.2828	0.062	1.221	0.2405	0.00537
1982	32.9	0.111	0.056	1.944	0.1308	0.00424
1983	32.7	0.0838	0.034	2.143	0.0679	0.00365
	32.7	0.159	0.051	1.769	0.146	0.004
	m^3/m^2	mg/L	mg/L	mg/L	mg/L	mg/L
	0.03266667	0.00487347	0.00155102	0.05416327	0.00448163	0.00013531
		207.2	51	27	63.546	112.4
		Pb mmole/L	V mmole/L	Al mmole/L	cu mmole/L	Cd mmole/L
		2.35E-05	3.04E-05	2.01E-03	7.05E-05	1.20E-06

CHEMISTRY OF PRECIPITATION - EAR FALLS, ONT.

YEAR	YEAR	Monthly Precip.	Free H+ mg/m^2	Sulfate mg/m^2	Cl mg/m^2	Nitrate N mg/m^2	NH4 N mg/m^2	Kjeldahl N mg/m^2	P mg/m^2
1981	1981	32.4	0.4249	49.54	3.867	9.864	13.63	17.201	1.2857
1982	1982	32.9	0.2766	41.17	3.142	7.99	8.583	21.748	0.9635
1983	1983	32.7	0.3814	48.02	2.496	8.848	7.126	11.347	0.5882
		32.7	0.361	46.243	3.168	8.901	9.780	16.765	0.946
		m^3/m^2	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
		0.03266667	0.01105	1.41561224	0.0969898	0.27246939	0.29937755	0.51322449	0.02895306
			1.0	96.06	35	14.0	14	14	31
			Free H+ Mole/L	Sulfate mmole/L	Cl mmole/L	NO3-N mmole/L	N mmole/L	NH4-N mmole/L	P mmole/L
			1.11E-05	1.47E-02	2.77E-03	1.95E-02	2.14E-02	3.67E-02	9.34E-04
			pH						
			4.96						

APPENDIX A

ANALYSES used in WATEQ4F and NETPATH modelling

Source : WH-SEEP - 92/07/14
Type : SEEP WATER

Date/time sampled : 92/07/14

Temperature	16. degrees C	Copper	8.29 mgll
Sp. Cond.	2650.	Nickel	N.D. mgll
pH	3.24	Nitrite-Nitrate	N.D. mgll as N
Eh	.536 volts	NH4 (Kjd)	N.D. mgll as N
Density	N.D. g/cm3	Phosphate	N.D. mgll as P
Dissolved Oxygen	N.D. mgll	Boron	N.D. mgll
Total carbon #	2. mgll	Aluminum	14.3 mgll
Calcium	513. mgll	Silica	50.5 mgll as Si02
Magnesium	153. mgll	DOC	N.D. mgll
Sodium	10.6 mgll	RS of DOC	N.D.
Potassium	11.3 mgll	CH4 (aq)	N.D. mgll
Barium	N.D. mg/l	Delta C-13 TDlC	N.D. *oloo*
Strontium	1.05 mg/l	Carbon 14 TDlC	N.D. % modern
Iron	38.5 mg/l	Delta S-34 (SO4)	N.D. *oloo*
Manganese	54.9 mg/l	Delta S-34 (H2S)	N.D. *oloo*
Zinc	919. mgll	Sr 87/86	N.D.
Chloride	N.D. mg/l	Delta Deuterium	N.D. *oloo*
Sulfate	3206. mg/l	Delta 0-18	N.D. *oloo*
Hydrogen Sulfide	N.D. mgll	Tritium	N.D. TU

EPMCAT 72.75 EPMAN 66.82 ERROR 4.24%
.....

N.D. = not determined or not detected
TDlC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = total carbon, reported as HCO3-

Source : WH-SEEP - 92/08/14
Type : SEEP WATER

Date/time sampled : 92/08/14

Temperature	16. degrees C	Copper	7.46 mgll
Sp. Cond.	3460.	Nickel	.28 mgll
pH	3.55	Nitrite-Nitrate	N.D. mgll as N
Eh	.349 volts	NH4 (Kjd)	N.D. mgll as N
Density	N.D. g/cm3	Phosphate	N.D. mgll as P
Dissolved Oxygen	N.D. mgll	Boron	1.57 mgll
Total carbon #	2. mgll	Aluminum	14.4 mgll
Calcium	483. mgll	Silica	52.2 mgll as SiO2
Magnesium	132. mgll	DOC	N.D. mgll
Sodium	9.14 mgll	RS of DOC	N.D.
Potassium	11.5 mgll	CH4 (aq)	N.D. mgll
Barium	.021 mgll	Delta C-13 TDIC	N.D. *oloo*
Strontium	.956 mgll	Carbon 14 TDIC	N.D. % modern
Iron	74.2 mgll	Delta S-34 (SO4)	N.D. *oloo*
Manganese	42. mgll	Delta S-34 (H2S)	N.D. *oloo*
Zinc	492. mgll	Sr 87/86	N.D.
Chloride	N.D. mgll	Delta Deuterium	N.D. *oloo*
Sulfate	2924. mgll	Delta 0-18	N.D. *oloo*
Hydrogen Sulfide	N.D. mgll	Tritium	N.D. TU

EPMCAT 56.92 EPMAN 60.95 ERROR -3.41%

N.D. = not determined or not detected
TDIC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = total carbon, reported as HCO3-

Source : BR-CAP - 92/07/14
Type : SHAFT WATER

Date/time sampled : 92/07/14

Temperature	15. degrees C	Copper	1.85 mgll
Sp. Cond.	1850.	Nickel	N.D. mgll
pH	5.61	Nitrite-Nitrate	N.D. mgll as N
Eh	.320 volts	NH4 (Kjd)	N.D. mgll as N
Density	N.D. g/cm3	Phosphate	N.D. mgll as P
Dissolved Oxygen	N.D. mg/l	Boron	N.D. mgll
Alkalinity #	11. mgll	Aluminum	3.46 mgll
Calcium	476. mgll	Silica	34.2 mgll as SiO2
Magnesium	129. mg/l	DOC	N.D. mgll
Sodium	9.97 mgll	RS of DOC	N.D.
Potassium	8.2 mgll	CH4 (aq)	N.D. mgll
Barium	N.D. mgll	Delta C-13 TDIC	N.D. o/oo
Strontium	N.D. mgll	Carbon 14 TDIC	N.D. % modern
Iron	19.5 mgll	Delta S-34 (SO4)	N.D. *oloo*
Manganese	55.3 mgll	Delta S-34 (H2S)	N.D. *oloo*
Zinc	642. mgll	Sr 87/86	N.D.
Chloride	N.D. mgll	Delta Deuterium	N.D. *oloo*
Sulfate	2490. mgll	Delta 0-18	N.D. *oloo*
Hydrogen Sulfide	N.D. mgll	Tritium	N.D. TU

EPMCAT 57.78 EPMAN 52.06 ERROR 5.21%

N.D. = not determined or not detected
TDIC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = uncorrected, reported as HCO3-

Source : BR-CAP - 92/08/13
Type : SHAFT WATER

Date/time sampled : 92/08/13

Temperature	16.9 degrees C	Copper	1.29 mgll
Sp. Cond.	2680.	Nickel	.24 mgll
pH	4.8	Nitrite-Nitrate	N.D. mgll as N
Eh	.178 volts	NH4 (Kjd)	N.D. mgll as N
Density	N.D. g/cm3	Phosphate	N.D. mgll as P
Dissolved Oxygen	N.D. mgll	Boron	N.D. mgll
Alkalinity #	10. mgll	Aluminum	2.83 mg/l
Calcium	474. mgll	Silica	36.15 mgll as SiO2
Magnesium	111. mgll	DOC	N.D. mgll
Sodium	9.84 mgll	RS of DOC	N.D.
Potassium	13.2 mgll	CH4 (aq)	N.D. mgll
Barium	.019 mgll	Delta C-13 TDIC	N.D. *oloo*
Strontium	.898 mgll	Carbon 14 TDIC	N.D. % modern
Iron	14.2 mgll	Delta S-34 (SO4)	N.D. *oloo*
Manganese	43.5 mgll	Delta S-34 (H2S)	N.D. *oloo*
Zinc	400. mgll	Sr 87/86	N.D.
Chloride	N.D. mgll	Delta Deuterium	N.D. *oloo*
Sulfate	2427. mgll	Delta 0-18	N.D. *oloo*
Hydrogen Sulfide	N.D. mgll	Tritium	N.D. TU

EPMCAT 48.26 EPMAN 50.73 ERROR -2.49%

.....

N.D. = not determined or not detected
TDIC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = uncorrected, reported as HCO3-

Source : MILL POND - 92/07/13
Type : OVERFLOW

Date/time sampled : 92/07/13

Temperature	22. degrees C	Copper	25.2 mgll
Sp. Cond.	2100.	Nickel	N.D. mgll
pH	3.25	Nitrite-Nitrate	N.D. mgll as N
Eh	.275 volts	NH4 (Kjd)	N.D. mgll as N
Density	N.D. g/cm3	Phosphate	N.D. mgll as P
Dissolved Oxygen	N.D. mgll	Boron	N.D. mgll
Total carbon #	2. mgll	Aluminum	12. mgll
Calcium	278. mgll	Silica	29.91 mgll as Si02
Magnesium	51.4 mgll	**DOC**	N.D. mgll
Sodium	3.35 mgll	RS of DOC	N.D.
Potassium	5.5 mgll	CH4 (aq)	N.D. mgll
Barium	N.D. mgll	Delta C-13 TDlC	N.D. *oloo*
Strontium	N.D. mgll	Carbon 14 TDlC	N.D. % modern
Iron	18.9 mgll	Delta S-34 (SO4)	N.D. *oloo*
Manganese	20.7 mgll	Delta S-34 (H2S)	N.D. *oloo*
Zinc	329. mg/l	Sr 87/86	N.D.
Chloride	N.D. mgll	Delta Deuterium	N.D. *oloo*
Sulfate	1495. mgll	Delta 0-18	N.D. *oloo*
Hydrogen Sulfide	N.D. mg/l	Tritium	N.D. TU

EPMCAT 32.18 EPMAN 31.18 ERROR 1.57%

N.D. = not determined or not detected
TDlC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = total carbon, reported as HCO3-

Source : MILL POND - 92-07-18
Type : OVERFLOW

Date/time sampled : 92/07/18

Temperature	22. degrees C	Copper	14. mgll
Sp. Cond.	1650.	Nickel	N.D. mgll
pH	3.65	Nitrite-Nitrate	N.D. mgll as N
Eh	.257 volts	NH4 (Kjd)	N.D. mgll as N
Density	N.D. g/cm3	Phosphate	N.D. mgll as P
Dissolved Oxygen	N.D. mgll	Boron	N.D. mgll
Total carbon #	2. mgll	Aluminum	6.61 mgll
Calcium	236. mgll	Silica	22. mgll as Si02
Magnesium	42. mgll	DOC	N.D. mgll
Sodium	3. mgll	RS of DOC	N.D.
Potassium	5.6 mgll	CH4 (aq)	N.D. mgll
Barium	N.D. mgll	Delta C-13 TDIC	N.D. *oloo*
Strontium	N.D. mgll	Carbon 14 TDIC	N.D. % modern
Iron	18.6 mgll	Delta S-34 (SO4)	N.D. *oloo*
Manganese	15.3 mgll	Delta S-34 (H2S)	N.D. *oloo*
Zinc	233. mgll	Sr 87/86	N.D.
Chloride	N.D. mgll	Delta Deuterium	N.D. *oloo*
Sulfate	1168.9 mgll	Delta 0-18	N.D. *oloo*
Hydrogen Sulfide	N.D. mgll	Tritium	N.D. TU

EPMCAT 25.04 EPMAN 24.38 ERROR 1.32%

N.D. = not determined or not detected
TDIC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = total carbon, reported as HCO3-

Source : MILL POND - 92/08/14
Type : OVERFLOW

Date/time sampled : 92/08/14

Temperature	17. degrees C	Copper	14.3 mgll
Sp. Cond.	1800.	Nickel	.08 mgll
pH	3.69	Nitrite-Nitrate	N.D. mgll as N
Eh	.310 volts	NH4 (Kjd)	N.D. mg/l as N
Density	N.D. g/cm3	Phosphate	N.D. mgll as P
Dissolved Oxygen	N.D. mgll	Boron	N.D. mgll
Total carbon #	2. mgll	Aluminum	6.41 mgll
Calcium	304. mgll	Silica	27.6 mgll as Si02
Magnesium	49.7 mgll	DOC	N.D. mgll
Sodium	3.02 mgll	RS of DOC	N.D.
Potassium	6. mgll	CH4 (aq)	N.D. mgll
Barium	.028 mg/l	Delta C-13 TDIC	N.D. *oloo*
Strontium	.386 mg/l	Carbon 14 TDIC	N.D. % modern
Iron	36.8 mgll	Delta S-34 (SO4)	N.D. *oloo*
Manganese	14.4 mgll	Delta S-34 (H2S)	N.D. o/oo
Zinc	191. mgll	Sr 87/86	N.D.
Chloride	N.D. mgll	Delta Deuterium	N.D. o/oo
Sulfate	1339. mgll	Delta 0-18	N.D. o/oo
Hydrogen Sulfide	N.D. mgll	Tritium	N.D. TU

EPMCAT 28.38 EPMAN 27.93 ERROR .81%

N.D. = not determined or not detected
TDIC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = total carbon, reported as HCO3-

Source : BR13-SEEP - 92/07/13
Type : SEEP WATER

Date/time sampled : 92/07/13

Temperature	22. degrees C	Copper	N.D. mg/l
Sp. Cond.	1600.	Nickel	N.D. mg/l
pH	3.63	Nitrite-Nitrate	N.D. mg/l as N
Eh	.248 volts	NH4 (Kjd)	N.D. mg/l as N
Density	N.D. g/cm3	Phosphate	N.D. mg/l as P
Dissolved Oxygen	N.D. mg/l	Boron	N.D. mg/l
Total carbon #	3.5 mg/l	Aluminum	11.6 mg/l
Calcium	221. mg/l	Silica	21.8 mg/l as SiO2
Magnesium	47.7 mg/l	DOC	N.D. mg/l
Sodium	4.55 mg/l	RS of DOC	N.D.
Potassium	6.4 mg/l	CH4 (aq)	N.D. mgll
Barium	N.D. mg/l	Delta C-13 TDlC	N.D. *oloo*
Strontium	N.D. mg/l	Carbon 14 TDlC	N.D. % modern
Iron	13.7 mg/l	Delta S-34 (SO4)	N.D. *oloo*
Manganese	18.6 mg/l	Delta S-34 (H2S)	N.D. *oloo*
Zinc	173. mg/l	Sr 87/86	N.D.
Chloride	N.D. mg/l	Delta Deuterium	N.D. *oloo*
Sulfate	1091. mg/l	Delta 0-18	N.D. *oloo*
Hydrogen Sulfide	N.D. mg/l	Tritium	N.D. TU

EPMCAT 23.30 EPMAN 22.79 ERROR 1.11%

.....

N.D. = not determined or not detected
TDlC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = total carbon, reported as HCO3-

Source : BR13-SEEP - 92-07-16
Type : SEEP WATER

Date/time sampled : 92/07/16

Temperature	19. degrees C	Copper	N.D. mg/l
Sp. Cond.	800.	Nickel	N.D. mg/l
pH	5.54	Nitrite-Nitrate	N.D. mg/l as N
Eh	.146 volts	NH4 (Kjd)	N.D. mg/l as N
Density	N.D. g/cm3	Phosphate	N.D. mg/l as P
Dissolved Oxygen	N.D. mg/l	Boron	N.D. mg/l
Alkalinity #	10. mg/l	Aluminum	1.48 mg/l
Calcium	118. mg/l	Silica	24. mg/l as Si02
Magnesium	26.7 mg/l	**DOC**	N.D. mg/l
Sodium	3. mg/l	RS of DOC	N.D.
Potassium	5. mg/l	CH4 (aq)	N.D. mg/l
Barium	N.D. mg/l	Delta C-13 TDIC	N.D. o/oo
Strontium	N.D. mg/l	Carbon 14 TDIC	N.D. % modern
Iron	4.31 mg/l	Delta S-34 (SO4)	N.D. o/oo
Manganese	9.04 mg/l	Delta S-34 (H2S)	N.D. *o/oo*
Zinc	84.2 mg/l	Sr 87/86	N.D.
Chloride	N.D. mg/l	Delta Deuterium	N.D. *o/oo*
Sulfate	506.4 mg/l	Delta 0-18	N.D. o/oo
Hydrogen Sulfide	N.D. mg/l	Tritium	N.D. TU

EPMCAT 11.57 EPMAN 10.71 ERROR 3.84%

.....

N.D. = not determined or not detected
TDIC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = uncorrected, reported as HCO3-

Source : BR13-SEEP - 92/08/14
Type : SEEP WATER

Date/time sampled : 92/08/14

Temperature	16. degrees C	Copper	1.02 mg/l
Sp. Cond.	1600.	Nickel	.12 mg/l
pH	3.61	Nitrite-Nitrate	N.D. mg/l as N
Eh	.384 volts	NH4 (Kjd)	N.D. mg/l as N
Density	N.D. g/cm3	Phosphate	N.D. mg/l as P
Dissolved Oxygen	N.D. mg/l	Boron	N.D. mg/l
Total carbon #	2. mg/l	Aluminum	12.6 mg/l
Calcium	240. mg/l	Silica	45.78 mg/l as Si02
Magnesium	53.5 mg/l	DOC	N.D. mg/l
Sodium	4.9 mg/l	RS of DOC	N.D.
Potassium	7.4 mg/l	CH4 (aq)	N.D. mg/l
Barium	.024 mg/l	Delta C-13 TDIC	N.D. o/oo
Strontium	.455 mg/l	Carbon 14 TDIC	N.D. % modern
Iron	20.6 mg/l	Delta S-34 (SO4)	N.D. o/oo
Manganese	17.9 mg/l	Delta S-34 (H2S)	N.D. o/oo
Zinc	163. mg/l	Sr 87/86	N.D.
Chloride	N.D. mg/l	Delta Deuterium	N.D. o/oo
Sulfate	1187. mg/l	Delta 0-18	N.D. o/oo
Hydrogen Sulfide	N.D. mg/l	Tritium	N.D. TU

EPMCAT 24.83 EPMAN 24.76 ERROR .14%

N.D. = not determined or not detected
TDIC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = total carbon, reported as HCO3-

Source : C13-Stn30 - 92/07/15
Type : BOTTOM WATER

Date/time sampled : 92/07/15

Temperature	12. degrees C	Copper	N.D. mgll
Sp. Cond.	850.	Nickel	N.D. mg/l
pH	5.78	Nitrite-Nitrate	N.D. mgll as N
Eh	.115 volts	NH4 (Kjd)	N.D. mgll as N
Density	N.D. g/cm3	Phosphate	N.D. mgll as P
Dissolved Oxygen	N.D. mgll	Boron	N.D. mgll
Alkalinity #	10. mgll	Aluminum	N.D. mgll
Calcium	129. mgll	Silica	8.6 mgll as SiO2
Magnesium	23.8 mgll	DOC	N.D. mg/l
Sodium	5.62 mgll	RS of DOC	N.D.
Potassium	6.1 mgll	CH4 (aq)	N.D. mgll
Barium	N.D. mgll	Delta C-13 TDIC	N.D. *oloo*
Strontium	N.D. mgll	Carbon 14 TDIC	N.D. % modern
Iron	2.88 mgll	Delta S-34 (SO4)	N.D. *oloo*
Manganese	10.6 mgll	Delta S-34 (H2S)	N.D. *oloo*
Zinc	71.3 mgll	Sr 87/86	N.D.
Chloride	N.D. mg/l	Delta Deuterium	N.D. *oloo*
Sulfate	527. mgll	Delta 0-18	N.D. *oloo*
Hydrogen Sulfide	N.D. mg/l	Tritium	N.D. TU

EPMCAT 11.47 EPMAN 11.14 ERROR 1.44%

N.D. = not determined or not detected
TDIC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = uncorrected, reported as HCO3-

Source : C13-Stn30 - 92/08/14
Type : BOTTOM WATER

Date/time sampled : 92/08/14

Temperature	16. degrees C	Copper	N.D. mgll
Sp. Cond.	1470.	Nickel	.1 mgll
pH	5.8	Nitrite-Nitrate	N.D. mgll as N
Eh	.085 volts	NH4 (Kjd)	N.D. mgll as N
Density	N.D. g/cm3	Phosphate	N.D. mgll as P
Dissolved Oxygen	N.D. mgll	Boron	N.D. mgll
Alkalinity #	10. mgll	Aluminum	N.D. mgll
Calcium	275. mgll	Silica	14.4 mgll as SiO2
Magnesium	46. mgll	DOC	N.D. mgll
Sodium	11.1 mgll	RS of DOC	N.D.
Potassium	9.6 mgll	CH4 (aq)	N.D. mgll
Barium	.029 mgll	Delta C-13 TDlC	N.D. *oloo*
Strontium	.764 mgll	Carbon 14 TDlC	N.D. % modern
Iron	20.6 mgll	Delta S-34 (SO4)	N.D. *oloo*
Manganese	21.1 mgll	Delta S-34 (H2S)	N.D. *oloo*
Zinc	142. mgll	Sr 87/86	N.D.
Chloride	N.D. mgll	Delta Deuterium	N.D. *oloo*
Sulfate	1073. mgll	Delta 0-18	N.D. *oloo*
Hydrogen Sulfide	N.D. mgll	Tritium	N.D. TU

EPMCAT 24.11 EPMAN 22.52 ERROR 3.41%

N.D. = not determined or not detected
TDlC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = uncorrected, reported as HCO3-

Source : PR-SEEP - 92/07/13
Type : SEEP WATER

Date/time sampled : 92/07/13

Temperature	22. degrees C	Copper	.5 mg/l
Sp. Cond.	800.	Nickel	N.D. mg/l
pH	5.62	Nitrite-Nitrate	N.D. mg/l as N
Eh	.162 volts	NH4 (Kjd)	N.D. mg/l as N
Density	N.D. g/cm3	Phosphate	N.D. mg/l as P
Dissolved Oxygen	N.D. mg/l	Boron	N.D. mgll
Alkalinity #	15. mg/l	Aluminum	N.D. mgll
Calcium	126. mg/l	Silica	14.8 mg/l as Si02
Magnesium	20.9 mg/l	DOC	N.D. mg/l
Sodium	3.3 mg/l	RS of DOC	N.D.
Potassium	4.1 mg/l	CH4 (aq)	N.D. mg/l
Barium	N.D. mg/l	Delta C-13 TDlC	N.D. *oloo*
Strontium	N.D. mg/l	Carbon 14 TDlC	N.D. % modern
Iron	N.D. mg/l	Delta S-34 (SO4)	N.D. *oloo*
Manganese	6.36 mg/l	Delta S-34 (H2S)	N.D. o/oo
Zinc	46.2 mg/l	Sr 87/86	N.D.
Chloride	N.D. mg/l	Delta Deuterium	N.D. o/oo
Sulfate	458. mg/l	Delta 0-18	N.D. o/oo
Hydrogen Sulfide	N.D. mg/l	Tritium	N.D. TU

EPMCAT 9.93 EPMAN 9.79 ERROR .70%

N.D. = not determined or not detected
TDlC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = uncorrected, reported as HCO3-

Source : PR-SEEP - 92/08/14
Type : SEEP WATER

Date/time sampled : 92/08/14

Temperature	15. degrees C	Copper	.578 mgll
Sp. Cond.	470.	Nickel	N.D. mgll
pH	5.64	Nitrite-Nitrate	N.D. mgll as N
Eh	.248 volts	NH4 (Kjd)	N.D. mgll as N
Density	N.D. g/cm3	Phosphate	N.D. mgll as P
Dissolved Oxygen	N.D. mg/l	Boron	N.D. mgll
Alkalinity #	10. mgll	Aluminum	.046 mgll
Calcium	90.7 mgll	Silica	18.4 mgll as SiO2
Magnesium	14.6 mgll	DOC	N.D. mgll
Sodium	2.76 mgll	RS of DOC	N.D.
Potassium	3.6 mgll	CH4 (aq)	N.D. mgll
Barium	.036 mgll	Delta C-13 TDlC	N.D. *o/oo*
Strontium	.243 mgll	Carbon 14 TDlC	N.D. % modern
Iron	.201 mgll	Delta S-34 (SO4)	N.D. o/oo
Manganese	3.85 mg/l	Delta S-34 (H2S)	N.D. o/oo
Zinc	22.2 mgll	Sr 87/86	N.D.
Chloride	N.D. mgll	Delta Deuterium	N.D. o/oo
Sulfate	298.7 mgll	Delta 0-18	N.D. o/oo
Hydrogen Sulfide	N.D. mgll	Tritium	N.D. TU

EPMCAT 6.79 EPMAN 6.39 ERROR 3.05%

N.D. = not determined or not detected
TDlC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = uncorrected, reported as HCO3-

Source : PR-CAP - 92/07/14
Type : SHAFT WATER

Date/time sampled : 92/07/14

Temperature	16. degrees C	Copper	N.D. mgll
Sp. Cond.	300.	Nickel	N.D. mgll
pH	7.81	Nitrite-Nitrate	N.D. mgll as N
Eh	.320 volts	NH4 (Kjd)	N.D. mg/l as N
Density	N.D. g/cm3	Phosphate	N.D. mgll as P
Dissolved Oxygen	N.D. mgll	Boron	N.D. mgll
Alkalinity #	130.5 mgll	Aluminum	N.D. mgll
Calcium	62.7 mgll	Silica	8.99 mgll as Si02
Magnesium	5.63 mgll	DOC	N.D. mgll
Sodium	8.63 mgll	RS of DOC	N.D.
Potassium	14.6 mgll	CH4 (aq)	N.D. mgll
Barium	N.D. mgll	Delta C-13 TDlC	N.D. *oloo*
Strontium	N.D. mgll	Carbon 14 TDlC	N.D. % modern
Iron	N.D. mgll	Delta S-34 (SO4)	N.D. *oloo*
Manganese	N.D. mgll	Delta S-34 (H2S)	N.D. *oloo*
Zinc	1.24 mgll	Sr 87/86	N.D.
Chloride	N.D. mgll	Delta Deuterium	N.D. *oloo*
Sulfate	73.7 mgll	Delta 0-18	N.D. *oloo*
Hydrogen Sulfide	N.D. mgll	Tritium	N.D. TU

EPMCAT 4.38 EPMAN 3.67 ERROR 8.75%

N.D. = not determined or not detected
TDlC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = uncorrected, reported as HCO3-

Source : PR-CAP - 92/08/14
Type : SHAFT WATER

Date/time sampled : 92/08/14

Temperature	17. degrees C	Copper	.038 mgll
Sp. Cond.	440.	Nickel	N.D. mgll
pH	6.28	Nitrite-Nitrate	N.D. mgll as N
Eh	.110 volts	NH4 (Kjd)	N.D. mgll as N
Density	N.D. g/cm3	Phosphate	N.D. mgll as P
Dissolved Oxygen	N.D. mgll	Boron	N.D. mgll
Alkalinity #	125. mgll	Aluminum	N.D. mgll
Calcium	86. mgll	Silica	9.52 mgll as Si02
Magnesium	9.72 mgll	DOC	N.D. mgll
Sodium	4.92 mgll	RS of DOC	N.D.
Potassium	9.5 mgll	CH4 (aq)	N.D. mgll
Barium	.041 mgll	Delta C-13 TDlC	N.D. o/oo
Strontium	.21 mg/l	Carbon 14 TDlC	N.D. % modern
Iron	.245 mgll	Delta S-34 (SO4)	N.D. o/oo
Manganese	.12 mgll	Delta S-34 (H2S)	N.D. o/oo
Zinc	2.95 mgll	Sr 87/86	N.D.
Chloride	N.D. mgll	Delta Deuterium	N.D. *oloo*
Sulfate	124. mgll	Delta 0-18	N.D. *oloo*
Hydrogen Sulfide	N.D. mgll	Tritium	N.D. TU

EPMCAT 5.66 EPMAN 4.63 ERROR 9.97%

N.D. = not determined or not detected
TDlC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = uncorrected, reported as HCO3-

Source : DISTILLED WATER
Type : DISTILLED WATER

Date/time sampled : 92/11/23

Temperature	15. degrees C	Copper	N.D. mgll
Sp. Cond.	N.D.	Nickel	N.D. mgll
pH	7.	Nitrite-Nitrate	N.D. mgll as N
Eh	.320 volts	NH4 (Kjd)	N.D. mgll as N
Density	N.D. g/cm3	Phosphate	N.D. mgll as P
Dissolved Oxygen	N.D. mgll	Boron	N.D. mgll
Alkalinity #	.0061 mgll	Aluminum	N.D. mgll
Calcium	N.D. mgll	Silica	N.D. mgll as SiO2
Magnesium	N.D. mgll	DOC	N.D. mgll
Sodium	N.D. mgll	RS of DOC	N.D.
Potassium	N.D. mgll	CH4 (aq)	N.D. mgll
Barium	N.D. mgll	Delta C-13 TDlC	N.D. *oloo*
Strontium	N.D. mgll	Carbon 14 TDlC	N.D. % modern
Iron	N.D. mgll	Delta S-34 (SO4)	N.D. *oloo*
Manganese	N.D. mgll	Delta S-34 (H2S)	N.D. *oloo*
Zinc	N.D. mgll	Sr 87/86	N.D.
Chloride	N.D. mgll	Delta Deuterium	N.D. *oloo*
Sulfate	N.D. mgll	Delta 0-18	N.D. *oloo*
Hydrogen Sulfide	N.D. mgll	Tritium	N.D. TU

EPMCAT .00 EPMAN .00 ERROR .01%

N.D. = not determined
TDlC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = uncorrected, reported as HCO3-

Source : PRECIPITATION
Type : WATER

Date/time sampled : 92/11/23

Temperature	15. degrees C	Copper	,004482 mgll
Sp. Cond.	N.D.	Nickel	.001166 mgll
pH	4.96	Nitrite-Nitrate	,272469 mgll as N
Eh	.320 volts	NH4 (Kjd)	.812 mgll as N
Density	N.D. g/cm3	Phosphate	,028953 mgll as P
Dissolved Oxygen	N.D. mgll	Boron	N.D. mgll
Total carbon #	1. mgll	Aluminum	,054163 mgll
Calcium	,191694 mgll	Silica	N.D. mgll as Si02
Magnesium	,041041 mgll	DOC	N.D. mgll
Sodium	.057561 mgll	RS of DOC	N.D.
Potassium	,068388 mgll	CH4 (aq)	N.D. mgll
Barium	N.D. mgll	Delta C-13 TDlC	N.D. *oloo*
Strontium	N.D. mgll	Carbon 14 TDlC	N.D. % modern
Iron	,064495 mgll	Delta S-34 (SO4)	N.D. *oloo*
Manganese	,00606 mgll	Delta S-34 (H2S)	N.D. *oloo*
Zinc	,008571 mgll	Sr 87/86	N.D.
Chloride	,09699 mgll	Delta Deuterium	N.D. *oloo*
Sulfate	1.415612 mgll	Delta 0-18	N.D. *oloo*
Hydrogen Sulfide	N.D. mgll	Tritium	N.D. TU

EPMCAT .08 EPMAN .07 ERROR 9.32%

.....

N.D. = not determined or not detected
TDlC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = total carbon, reported as HCO3-

Source : GRAVEL PIT - 92/08/13
Type : POND WATER

Date/time sampled : 92/08/13

Temperature	20. degrees C	Copper	.005 mgll
Sp. Cond.	75.	Nickel	N.D. mgll
pH	7.5	Nitrite-Nitrate	N.D. mgll as N
Eh	.320 volts	NH4 (Kjd)	N.D. mgll as N
Density	N.D. g/cm3	Phosphate	N.D. mgll as P
Dissolved Oxygen	N.D. mgll	Boron	N.D. mgll
Alkalinity #	41.5 mgll	Aluminum	.038 mgll
Calcium	13.9 mgll	Silica	.727 mgll as SiO2
Magnesium	1.91 mg/l	DOC	N.D. mg/l
Sodium	1.38 mgll	RS of DOC	N.D.
Potassium	3.6 mgll	CH4 (aq)	N.D. mgll
Barium	.021 mgll	Delta C-13 TDlC	N.D. *oloo*
Strontium	.04 mgll	Carbon 14 TDlC	N.D. % modern
Iron	.071 mgll	Delta S-34 (SO4)	N.D. *oloo*
Manganese	.022 mgll	Delta S-34 (H2S)	N.D. *oloo*
Zinc	.054 mgll	Sr 87/86	N.D.
Chloride	N.D. mgll	Delta Deuterium	N.D. *oloo*
Sulfate	7.94 mgll	Delta 0-18	N.D. *oloo*
Hydrogen Sulfide	N.D. mgll	Tritium	N.D. TU

EPMCAT 1.01 EPMAN .85 ERROR 9.03%

N.D. = not determined or not detected
TDlC = Total Dissolved Inorganic Carbon
DOC = Dissolved Organic Carbon
Sp. Cond. = Specific Conductivity (uS/cm)
RS = Redox State
# = uncorrected, reported as HCO3-

SATURATION INDICES (SI) from WATEQ4F

MINERAL	WHS		BRC		MP		BR13		C13-30		PRS		PRC		GRAVELPIT
	14/07	14/08	14/07	13/08	13/07	14/08	13/07	14/08	15/07	14/08	13/07	14/08	14/07	14/08	13/08
ADULARIA			1.04												
ALLOPHANE			1.166									0.349			0.463
ALUNITE			9.074				0.102					3.506			
ANNITE	17.521	49.674	54.986	51.465	5.458	48.41	16.723	48.537				47.409			37.681
BARITE		0.406		0.334		0.448		0.391		0.461		0.417		0.188	0.878
BASALUMINITE			9.157	0.953								3.16			
BEIDELLITE			7.368	1.627								3.132			
BOEHMITE			2.015	-0.308								0.677			
CHALCEDONY	0.595	0.608	0.436	0.436	0.289	0.314	0.15	0.545	-0.133	0.043	0.02	0.159			
CRISTOBALITE	0.648	0.661	0.491	0.487	0.331	0.365	0.192	0.599	-0.071	0.096	0.021	0.214			
CU-METAL			9.622	0.305							0.929			0.741	
CUPROUS FERRITE	3.045	4.532	11.598	8.084	3.697	5.346		3.629				9.783		10.607	11.871
DIASPORE			3.809	1.469								2.471			2.627
GIBBSITE			2.626	0.276								1.288			1.42
GOETHITE	3.103	1.065	6.182	1.154	1.574	0.622	-0.992	1.434	2.432	2.801		3.299		2.93	7.842
GYPSUM	-0.013	-0.013	-0.062	-0.043	0.366	-0.317	-0.498	-0.431	-0.612	-0.389					
HEMATITE	7.511	3.435	13.588	3.686	1.371	2.629	-0.205	4.172	5.841	6.907		7.822		7.245	17.306
MAGNETITE	2.081	-1.084	12.587						4.404	6.475		5.166		6.051	16.298
PYROPHILLITE	-1.511	0.381	10.517	6.106	0.838	0.111	1.034	0.957				6.732			1.881
QUARTZ	1.053	1.066	0.897	0.891	0.727	0.768	0.589	1.003	0.338	0.501	0.418	0.62	0.29	0.302	-0.864
ZN-SILICATE	-2.419	-2.059	1.985	0.266	2.672	-2.28	-2.28	-2.315	0.863	1.514	1.075	0.626	3.26	0.831	0.666
HALLOYSITE			2.648												
ILLITE			4.945												
JURBANITE			1.14	0.326											
KAOLINITE			7.828	3.123								4.598			1.916
K-MICA			11.846												4.688
LAUMONTITE			2.93												
LEONARDITE			13.972												0.937
MAGHEMITE			3.979												7.298
CA-MONTMORILLONI			7.122	1.401								2.923			

APPENDIX C

OUTPUT from NETPATH modelling

Initial Source : PRECIPITATION
Final Source : WH-SEEP - 92/07/14

	Final	Initial	(millimole/L)
S	33.5415	.0147	
CU	.1311	.0001	
SI	.8447	.0000	
ZN	14.1288	.0001	
FE	.6928	.0012	
RS	202.6379	.0907	
NA	.4634	.0025	
AL	.5327	.0020	

CHALCOPYCU - 1.0000 FE - 1.0000 S - 2.0000 RS - 2.0000
GOETHITEFE - 1.0000 RS - 3.0000
02 GAS RS - 4.0000
SFALERITZN - 1.0000 S - 1.0000 RS - 2.0000
SiO2 SI - 1.0000
PYRITE FE - 1.0000 S - 2.0000 RS - .0000 I3 - 60.0000
PLAGAN38CA - .3800 NA - ,6200 AL - 1.3800 SI - 2.6200
GIBBSITEAL - 1.0000

MODEL 1 (- indicates precipitation)

CHALCOPY +	,13104
GOETHITE -	-9.00736
02 GAS +	64.52217
SFALERIT +	14.12870
SiO2 -	-1.10290
PYRITE +	9.56801
PLAGAN38	.74335
GIBBSITE	-.49519

Data used for Carbon-I3
Insufficient data

Data used for C-14 (% mod)
Insufficient data

Data used for Sulfur-34
Insufficient data

Data used for Strontium-87
Insufficient data

1 models were tested.
1 models were found which satisfied the constraints.

Initial Source : GRAVEL PIT - 92/08/13
Final Source : WH-SEEP - 92/07/14

	Final	Initial (millimole/L)
S	33.5415	.0827
CU	.1311	.0001
SI	.8447	.0121
ZN	14.1288	.0008
FE	.6928	.0013
RS	202.6379	.4998
NA	.4634	.0600
AL	.5327	.0014

CHALCOPYCU - 1.0000 FE - 1.0000 S - 2.0000 RS - 2.0000
GOETHITEFE - 1.0000 RS - 3.0000
02 GAS RS - 4.0000
SFALERITZN - 1.0000 S - 1.0000 RS - 2.0000
Si02 SI - 1.0000
PYRITE FE - 1.0000 S - 2.0000 RS -.0000 I3 - 60.0000
PLAGAN38CA - ,3800 NA - .6200 AL - 1.3800 SI - 2.6200
GIBBSITEAL 1.0000

MODEL 1 (- indicates precipitation)

CHALCOPY +	.13103
GOETHITE -	-8.97387
02 GAS +	64.39444
SFALERIT +	14.12800
SiO2 -	-.87189
PYRITE +	9.53441
PLAGAN38	.65056
GIBBSITE	-.36654

Data used for Carbon-I3
Insufficient data

Data used for C-14 (% mod)
Insufficient data

Data used for Sulfur-34
Insufficient data

Data used for Strontium-87
Insufficient data

1 models were tested.
1 models were found which satisfied **the** constraints.

Initial Source : GRAVEL PIT - 92/08/13
Final Source : WH-SEEP - 92/08/14

	Final	Initial	(millimole/L)
S	30.5686	.0827	
CU	.1179	.0001	
SI	.8725	.0121	
ZN	7.5585	.0008	
FE	1.3343	.0013	
RS	186.0803	.4998	
NA	.3993	.0600	
AL	.5360	.0014	

CHALCOPYCU - 1.0000	FE - 1.0000	S - 2.0000	RS - 2.0000
02 GAS RS - 4.0000			
SFALERITZN - 1.0000	S - 1.0000	RS - 2.0000	
SiO2 SI - 1.0000			
PYRITE FE - 1.0000	S - 2.0000	RS - .0000	I3 - 60.0000
PLAGAN38CA - .3800	NA - .6200	AL - 1.3800	SI - 2.6200
GIBBSITEAL - 1.0000			
HEMATITEFE - 2.0000	RS - 6.0000		

MODEL 1 (- indicates precipitation)

CHALCOPY +	.11782
02 GAS +	57.83120
SFALERIT +	7.55766
SiO2 -	-.57314
PYRITE +	11.34633
PLAGAN38	.54715
GIBBSITE	-.22049
HEMATITE -	-5.06556

Data used for Carbon-I3
Insufficient data

Data used for C-14 (% mod)
Insufficient data

Data used for Sulfur-34
Insufficient data

Data used for Strontium-87
Insufficient data

1 models were tested.
1 models were found which satisfied the constraints.

Initial Source : PRECIPITATION
Final Source : BR-CAP - 92/07/14

	Final	Initial (millimole/L)
S	26.0218	.0147
CU	.0292	.0001
SI	.5714	.0000
ZN	9.8593	.0001
FE	.3505	.0012
RS	156.8337	.0907
NA	.4354	.0025
AL	.1287	.0020

CHALCOPYCU - 1.0000	FE - 1.0000	S - 2.0000	RS - 2.0000
GOETHITEFE - 1.0000	RS - 3.0000		
02 GAS RS - 4.0000			
SFALERITZN - 1.0000	S - 1.0000	RS - 2.0000	
SiO2 SI - 1.0000			
PYRITE FE - 1.0000	S - 2.0000	RS - .0000	I3 - 60.0000
PLAGAN38CA - .3800	NA - .6200	AL - 1.3800	SI - 2.6200
GIBBSITEAL - 1.0000			

MODEL 1 (- indicates precipitation)

CHALCOPY +	.02916
GOETHITE -	-7.72459
02 GAS +	49.92335
SFALERIT +	9.85915
SiO2 -	-1.25777
PYRITE +	8.04482
PLAGAN38	.69816
GIBBSITE	-.83673

Data used for Carbon-I3
Insufficient data

Data used for C-14 (% mod)
Insufficient data

Data used for Sulfur-34
Insufficient data

Data used for Strontium-87
Insufficient data

1 models were tested.
1 models were found which satisfied the constraints.

Initial Source : GRAVEL PIT - 92/08/13
Final Source : BR-CAP - 92/07/14

	Final	Initial	(millimole/L)
S	26.0218	.0827	
CU	.0292	.0001	
SI	.5714	.0121	
ZN	9.8593	.0008	
FE	.3505	.0013	
RS	156.8337	.4998	
NA	.4354	.0600	
AL	.1287	.0014	

CHALCOPYCU - 1.0000	FE - 1.0000	S - 2.0000	RS - 2.0000
GOETHITEFE - 1.0000	RS - 3.0000		
02 GAS RS - 4.0000			
SFALERITZN - 1.0000	S - 1.0000	RS - 2.0000	
SiO2 SI - 1.0000			
PYRITE FE - 1.0000	S - 2.0000	RS - .0000	13 - 60.0000
PLAGAN38CA - .3800	NA - ,6200	AL - 1.3800	SI - 2.6200
GIBBSITEAL - 1.0000			

MODEL 1 (- indicates precipitation)

CHALCOPY +	.02915
GOETHITE -	-7.69110
02 GAS +	49.79561
SFALERIT +	9.85845
Si02 -	-1.02676
PYRITE +	8.01122
PLAGAN38	,60537
GIBBSITE	-.70808

Data used for Carbon-I3
Insufficient data

Data used for C-14 (% mod)
Insufficient data

Data used for Sulfur-34
Insufficient data

Data used for Strontium-87
Insufficient data

1 models were tested.
1 models were found which satisfied the constraints

Initial Source 1 : WH-SEEP - 92/08/14
Initial Source *2* : GRAVEL PIT - 92/08/13
Final Source : PR-CAP - 92/08/14

	Final	Initial 1	Initial *2*	(millimole/L)
S	1.2913	30.5686	.0827	
CU	.0006	.1179	.0001	
SI	.1585	.8725	.0121	
ZN	.0451	7.5585	.0008	
FE	.0044	1.3343	.0013	
RS	7.7567	186.0803	.4998	

GOETHITEFE - 1.0000 RS - 3.0000
02 GAS RS - 4.0000
ZINKITE ZN - 1.0000
CUSULFATCU - 2.0000 C - 1.0000 RS - **4.0000**
PLAGAN38CA - ,3800 NA - ,6200 AL - 1.3800 SI - 2.6200

MODEL 1 (- indicates precipitation)

INIT 1 + F	,03965
INIT *2* + F	,96035
GOETHITE -	-.04973
O2 GAS +	.01420
ZINKITE -	-.25532
CUSULFAT -	-.00208
PLAGAN38	.04286

Data used for Carbon-I3
Insufficient data

Data used for C-14 (% mod)
Insufficient data

Data used for Sulfur-34
Insufficient data

Data used for Strontium-87
Insufficient data

1 models were tested.
1 models were found which satisfied the constraints.

Initial Well 1 : BR-CAP - 92/08/13
Initial Well 2 : GRAVEL PIT - 92/08/13
Final Well : PR-CAP - 92/08/14

	Final	Initial 1	Initial 2	(millimole/L)
S	1.2913	25.3549	.0827	
CU	,0006	.0204	.0001	
SI	.1585	.6038	.0121	
ZN	.0451	6.1408	.0008	
FE	.0044	.2552	.0013	
RS	7.7567	152.6397	.4998	

GOETHITEFE - 1.0000 RS - 3.0000
02 GAS RS - 4.0000
ZINKITE ZN - 1.0000
CUSULFATCU - 2.0000 C - 1.0000 RS - 4.0000
PLAGAN38CA - .3800 NA - ,6200 AL - 1.3800 SI - 2.6200

MODEL 1 (- indicates precipitation)

INIT 1 + F	.04783
INIT 2 + F	.95217
GOETHITE -	-.00902
O2 GAS +	,00218
ZINKITE -	-.24934
CUSULFAT -	-.00023
PLAGAN38	,04508

Data used for Carbon-I3
Insufficient data

Data used for C-14 (% mod)
Insufficient data

Data used for Sulfur-34
Insufficient data

Data used for Strontium-87
Insufficient data

1 models were tested.
1 models were found which satisfied the constraints.

Initial Source 1 : WH-SEEP - 92/07/14
Initial Source 2 : GRAVEL PIT - 92/08/13
Final Source : PR-SEEP - 92/07/13

	Final	Initial 1	Initial 2	(millimole/L)
S	4.7711	33.5415	.0827	
CU	.0236	.1311	.0001	
SI	.2465	.8447	.0121	
ZN	.7072	14.1288	.0008	
FE	.0000	.6928	.0013	
RS	28.6266	202.6379	.4998	

GOETHITEFE - 1.0000 RS - 3.0000
02 GAS RS - 4.0000
ZINKITE ZN - 1.0000
PLAGAN38CA - ,3800 NA - ,6200 AL - 1.3800 SI - 2.6200
CHALCOPYCU - 1.0000 FE - 1.0000 S - 2.0000 RS - 2.0000

MODEL 1 (- indicates precipitation)

INIT 1 + F	.13981
INIT 2 + F	.86019
GOETHITE -	-.10318
02 GAS +	,04630
ZINKITE -	-1.26887
PLAGAN38 +	,04503
CHALCOPY +	.00522

Data used for Carbon-I3
Insufficient data

Data used for C-14 (% mod)
Insufficient data

Data used for Sulfur-34
Insufficient data

Data used for Strontium-87
Insufficient data

1 models were tested.
1 models were found which satisfied the constraints.

Initial Well : PR-SEEP - 92/07/13
Final Well : PR-SEEP - 92/08/14

	Final	Initial	(millimole/L)
S	3.1109	4.7711	
ZN	.3398	.7072	
FE	,0036	.0000	
RS	18.8129	28.8583	
MN	.0701	.1158	
CU	.0091	.0236	

02 GAS RS - 4.0000
MnOOH MN - 1.0000 RS - 3.0000
ZINKITE ZN - 1.0000
CUSULFATCU - 1.0000 S - 1.0000 RS - 6.0000
PYRITE FE - 1.0000 S - 2.0000 RS - .0000 I3 - 60.0000

MODEL 1 (- indicates precipitation)

02 GAS +	,01395
MnOOH	-.00540
ZINKITE -	-.12125
CUSULFAT -	-.00630
PYRITE +	,00360
Dilution factor:	1.534

Data used for Carbon-I3
Insufficient data

Data used for C-14 (% mod)
Insufficient data

Data used for Sulfur-34
Insufficient data

Data used for Strontium-87
Insufficient data

1 models were tested.
1 **models** were found which satisfied the constraints.

Initial Source : PRECIPITATION
Final Source : MILL POND - 92/07/13

	Final	Initial	(millimole/L)
S	15.5984	.0147	
CU	,3975	.0001	
SI	.4989	.0000	
ZN	5.0444	.0001	
FE	.3392	.0012	
RS	94.2685	.0907	
NA	.1461	.0025	

02 GAS RS - 4.0000

PLAGAN38CA - .3800	NA - .6200	AL - 1.3800	SI - 2.6200
CHALCOPYCU - 1.0000	FE - 1.0000	S - 2.0000	RS - 2.0000
PYRITE FE - 1.0000	S - 2.0000	RS - .0000	I3 - 60.0000
SFALERITZN - 1.0000	S - 1.0000	RS - 2.0000	
GOETHITEFE - 1.0000	RS - 3.0000		
SiO2 SI - 1.0000			

MODEL 1	(- indicates precipitation)
02 GAS +	29.96399
PLAGAN38 +	.23153
CHALCOPY +	,39740
PYRITE +	4.87230
SFALERIT +	5.04422
GOETHITE -	-4.93166
Si02 -	-.10768

Data used for Carbon-I3
Insufficient data

Data used for C-14 (% mod)
Insufficient data

Data used for Sulfur-34
Insufficient data

Data used for Strontium-87
Insufficient data

1 models were tested.
1 models were found which satisfied the constraints.

Initial Source : MILL POND - 92/07/13
Final Source : MILL POND 92-07-18

	Final	Initial (millimole/L)
S	12.1898	15.5984
ZN	3.5706	5.0444
RS	73.6966	94.3454
MN	.2790	.3776
CU	.2207	.3975

GOETHITEFE - 1.0000 RS - 3.0000
02 GAS RS - 4.0000
MnOOH MN - 1.0000 RS - 3.0000
CUSULFATCU - 2.0000 C - 1.0000 RS - 4.0000
ZINKITE ZN - 1.0000

MODEL 1 (- indicates precipitation)

02 GAS	.04899
MnOOH -	-.01613
CUSULFAT -	-.04496
ZINKITE -	-.37141
Dilution factor:	1.280

Data used for Carbon-I3
Insufficient data

Data used for C-14 (% mod)
Insufficient data

Data used for Sulfur-34
Insufficient data

Data used for Strontium-87
Insufficient data

5 models were tested.
1 models were found which satisfied the constraints

Initial Source 1 : MILL POND - 92/07/13
Initial Source 2 : PRECIPITATION
Final Source : MILL POND - 92/08/14

	Final	Initial 1	Initial 2	(millimole/L)
S	13.9668	15.5984	.0147	
CU	.2255	.3975	.0001	
SI	.4603	.4989	.0000	
ZN	2.9277	5.0444	.0001	
RS	83.8010	93.5901	.0884	
NA	,1316	.1461	.0025	
AL	.2381	.4458	.0020	

GIBBSITEAL - 1.0000
CUSULFATCU - 2.0000 S - 1.0000 RS - 6.0000
ZINKITE ZN - 1.0000
PLAGAN38CA - ,3800 NA - .6200 AL - 1.3800 SI - 2.6200
SiO2 SI - 1.0000
GYPSUM CA - 1.0000 S - 1.0000 RS - 6.0000 I3 - 22.0000
GOETHITEFE - 1.0000 RS - 3.0000

MODEL 1 (- indicates precipitation)

INIT 1 + F	.89954
INIT 2 + F	,10046
GIBBSITE	-.16313
CUSULFAT -	-.06603
ZINKITE -	-1.60995
PLAGAN38 +	.00000
SiO2	,01146
GOETHITE	.00000

MODEL 2 (- indicates precipitation)

INIT 1 + F	.89955
INIT 2 + F	,10045
GIBBSITE	-.16313
CUSULFAT	-.06604
ZINKITE -	-1.60997
SiO2	,01146
GYPSUM -	-.00007
GOETHITE	.00000

7 models were tested.
2 models were found which satisfied the constraints,

Initial Source 1 : BR-CAP - 92/07/14
Initial Source 2 : GRAVEL PIT - 92/08/13
Final Source : BR13-SEEP - 92/07/13

	Final	Initial 1	Initial 2	(millimole/L)
S	11.3756	26.0218	.0827	
CU	.0000	.0292	.0001	
SI	.3634	.5714	.0121	
ZN	2.6508	9.8593	.0008	
FE	.2457	.3505	.0013	
RS	69.4232	158.8547	.5006	
MN	.3391	1.0105	.0004	

02 GAS RS - 4.0000
ZINKITE ZN - 1.0000
MnOOH MN - 1.0000 RS - 3.0000
CUFERRITCU - 1.0000 FE - 1.0000 RS - 3.0000
PLAGAN38CA - .3800 NA - .6200 AL - 1.3800 SI - 2.6200
PYRITE FE - 1.0000 S - 2.0000 RS - .0000 I3 - 60.0000

MODEL 1 (- indicates precipitation)

INIT 1 + F	.42705
INIT 2 + F	,57295
02 GAS +	,40324
ZINKITE -	-1.56014
MnOOH -	-.09265
CUFERRIT -	-.01253
PLAGAN38 +	,04292
PYRITE +	,10782

Data used for Carbon-I3
Insufficient data

Data used for C-14 (% mod)
Insufficient data

Data used for Sulfur-34
Insufficient data

Data used for Strontium-87
Insufficient data

1 models were tested.
1 models were found which satisfied the constraints.

Initial Source : BR13-SEEP - 92/07/13
Final Source : BR13 SEEP 92-07-16

	Final	Initial (millimole/L)
S	5.2758	11.3756
ZN	1.2891	2.6508
RS	32.1386	69.4232
FE	,0772	.2457
MN	.1647	.3391

GOETHITEFE - 1.0000 RS - 3.0000
0 2 GAS RS - 4.0000
SFALERITZN - 1.0000 S - 1.0000 RS - 2.0000
MnOOH MN - 1.0000 RS - 3.0000

MODEL 1 (- indicates precipitation)

GOETHITE -	-.03503
0 2 GAS	,16203
SFALERIT +	,07784
MnOOH	.00972
Dilution factor:	2.188

Data used for Carbon-I3
Insufficient data

Data used for C-14 (% mod)
Insufficient data

Data used for Sulfur-34
Insufficient data

Data used for Strontium-87
Insufficient data

1 models were tested.
1 models were found which satisfied the constraints.

Initial Source 1 : BR-CAP - 92/07/14
Initial Source 2 : GRAVEL PIT - 92/08/13
Final Source : C13-Stn30 - 92/08/14

	Final	Initial 1	Initial 2	(millimole/L)
S	11.1881	26.0218	.0827	
CU	.0000	.0292	.0001	
SI	.2401	.5714	.0121	
ZN	2.1758	9.8593	.0008	
FE	.3695	.3505	.0013	
RS	68.6365	158.8547	.5006	
MN	,3847	1.0105	.0004	

0 2 GAS RS - 4.0000
ZINKITE ZN - 1.0000
MnOOH MN - 1.0000 RS - 3.0000
CUFERRITCU - 1.0000 FE - 1.0000 RS - 3.0000
PYRITE FE - 1.0000 S - 2.0000 RS - .0000 I3 - 60.0000
Si02 SI - 1.0000

MODEL 1 (- indicates precipitation)

INIT 1 + F	,40985
INIT 2 + F	.59015
0 2 GAS +	.83976
ZINKITE -	-1.86558
MnOOH -	-.02970
CUFERRIT	-.01203
PYRITE +	,23707
Si02 -	-.00129

Data used for Carbon-I3
Insufficient data

Data used for C-14 (% mod)
Insufficient data

Data used for Sulfur-34
Insufficient data

Data used for Strontium-87
Insufficient data

1 models were tested.
1 models were found which satisfied the constraints.

Initial Source : C13-Stn30 - 92/08/14
Final Source : C13-Stn30 - 92/07/15

	Final	Initial (millimole/L)
S	5.4904	11.1881
ZN	1.0916	2.1758
RS	33.4320	68.6365
FE	.0516	.3695
MN	.1931	.3847

GOETHITEFE - 1.0000 RS - 3.0000
02 GAS RS - 4.0000
SFALERITZN - 1.0000 S - 1.0000 RS - 2.0000
MnOOH MN - 1.0000 RS - 3.0000

MODEL 1 (- indicates precipitation)

GOETHITE -	-.12872
02 GAS	.09007
SFALERIT +	,02959
MnOOH	,00533
Dilution factor:	2.049

Data used for Carbon-I3
Insufficient data

Data used for C-14 (% mod)
Insufficient data

Data used for Sulfur-34
Insufficient data

Data used for Strontium-87
Insufficient data

1 models were tested.
1 models were found which satisfied the constraints,

APPENDIX D BOOJUM **QNQC** INFORMATION

Methods for field sampling and the storage and handling of samples are summarised in MEND summary report, February 1990. The MEND document also describes methods used for determinations of pH, conductivity, acidity and alkalinity, and information on calibration, etc. The method for Eh determination is available on request. Microbiology and analytical chemistry methods carried out at Dearborn are summarised in the following MEND reports:DSS **23440-8-905/015Q (1988); DSS 0395Q.23440-8-9264** (June **1990);** DSS **0145Q.23440-0-9065** (March **1991).**

External quality control (quality assurance)

Cation/anion balances of both water and solid samples were carried out by ICP (Inductively Coupled Plasma Spectrophotometry), U.S. EPA Method No.200.7 at certified laboratories. The QA/QCs of EPL and X-Ral are available on request. To assure the validity of the results, blanks and standards were sent together with field samples. These samples were packaged and marked as per the field samples. Standards with different concentrations of metals were sent **(0.1, 1, 10, 100, 1000** mg L^{-1} of metals) every few months. The composition of the standards and the procedure for sending these samples to Chauncey Laboratories are available on request. U.S. National Bureau of Standards **1645** (River Sediment) and **1571** (Orchard Leaves) samples were sent as solid standards. The quality control data for these is available on request. In **1991, 12** standards were sent to Chauncey laboratories and **24** to X-Ral. In **1992,** one Al standard and **4** Boojum standards were sent to X-Ral and **18** standards were sent to EPL. The standard analyses were not consistently accurate for any of the three laboratories. These results and those of field samples were thoroughly screened on receipt and where obvious inaccuracies or anomalies were detected, the laboratory was informed, the errors explained and the samples reanalysed.

Copies in Mend Report

APPENDIX E Water and Sediment ICP Data

WATER ANALYSIS IN MILL POND STATION 7

SAMPLE DATE		13-Jul-92	16-Jul-92	
SAMPLE VOLUME		100	100	
ASSAYERS CODE		3844	3958	
SAMPLING LOCATION		SOUTH BAY Mill Pond MPC7 bottom	SOUTH BAY Mill Pond MPC7 bottom	
Processing code		FA	FA	
** F I E L D **				
Temp. (C)		23		
pH		5.75		
Cond. (umhos/cm)		3300		
Eh (mV)		-49		
Acidity (mg/l)				
Alkalinity (mg/l)				
Ferric (Fe3+)				
Ferrous (Fe2+)				
** L A B **				
Temp. (C)				
pH		6.11	6.07	
Cond. (umhos/cm)		1850		
Eh (mV)				
Acidity (mg/l)		1185	750	
Alkalinity (mg/l)		82.5		
Ferric (Fe3+)				
Ferrous (Fe2+)				
ELEMENTS	Ag <	1	0.005	
	Al	6.28	0.191	
	As <	1	< 0.5	
	B <	1	< 0.01	
	Ba <	1	0.013	
	Be <	1	< 0.005	
	Bi <	1	< 0.05	
	C			
	Ca	464	590	
	Cd <	1	0.393	
	Ce			
	Co <	1	0.646	
	Cr <	1	0.016	
	Cu	2.31	0.238	
	Fe	275	0.203	
	Hg			
	K	20.4	15.8	
	La			
	Mg	121	141	
	Mn	49.6	47.7	
	Mo <	1	< 0.01	
	Na	7.26	40.5	
	Nb			
	Ni <	1	0.18	
	P <	1	< 0.06	
	Pb <	1	0.073	
	S	929	866	
	Sb			
	Se <	1	< 0.5	
	Si	16.31	6.4	
	Sn <	1	0.71	
	Sr <	1	0.969	
	Te			
	Th			
	Ti <	1	< 0.05	
	U			
	V <	1	< 0.01	
	W			
	Y			
	Zn	625	334	
	Zr			
TIC		1	3.3	

WATER ANALYSES IN TAILINGS AREA

SAMPLE DATE	16-Jul-92	18-Jul-92	13-Aug-92	13-Aug-92	17-Oct-92	17-Oct-92
SAMPLE VOLUME	100	100	100	100	100	100
ASSAYERS CODE	3861	3865	4033	4034	4237	4238
SAMPLING LOCATION	SOUTH BAY Tailings TRO	SOUTH BAY Tailings TRO	SOUTH BAY Tailings TRO	SOUTH BAY Tailings TRO	SOUTH BAY Tailings TRO	SOUTH BAY Tailings TRO
Processing code	surface FA	surface FA	no phosph. FA	phosph. FA	pre FA	past FA
** F I E L D **						
Temp. (C)	19	22	20.3	20	21.4	21.2
pH	2.96	4.74	2.4	4.2	2.53	3.24
Cond. (umhos/cm)	1950	2200	4600	3400	3820	3140
Eh (mV)	410	151			398	367
Acidity (mg/l)	580	410				
Alkalinity (mg/l)						
Ferric (Fe3+)						
Ferrous (Fe2+)						
** L A B **						
Temp. (C)			14	15		
pH			2.83	4.55	2.44	3.16
Cond. (umhos/cm)			3500	2450		
Eh (mV)			468	285		
Acidity (mg/l)			2620	797.5	2588	717
Alkalinity (mg/l)						
Ferric (Fe3+)						
Ferrous (Fe2+)						
ELEMENTS Ag	< 1	< 1	0.017	< 0.003	0.019	0.005
Al	34.3	5.19	96.5	57.5	45.7	29.8
As	< 1	< 1	< 0.5	< 0.5		
B	< 1	< 1	0.01	0.01	< 0.01	< 0.01
Ba	< 1	< 1	0.013	0.022	0.005	0.006
Be	< 1	< 1	< 0.005	< 0.005	< 0.005	< 0.005
Bi	< 1	< 1	< 0.05	< 0.05	< 0.05	< 0.05
C						
Ca	303	461	318	564	253	516
Cd	< 1	< 1	< 0.003	0.25	< 0.003	0.139
Ce						
Co	< 1	< 1	0.41	0.576	0.431	0.495
Cr	< 1	< 1	0.128	0.014	0.078	0.021
Cu	< 1	3.78	1.32	4.7	0.764	1.77
Fe	53.5	12.9	552	1.3	648	25.9
Hg						
K	4.7	5.4	2.3	6.4	2.8	3.1
La						
Mg	58.6	79.3	107	95.9	77.2	78.5
Mn	11.8	14.9	21.6	20.4	19	17.2
Mo	< 1	< 1	< 0.01	< 0.01	< 0.01	0.01
Na	11.1	11.2	10.7	13	9.3	10.1
Nb						
Ni	< 1	< 1	0.24	0.28	0.16	0.24
P	< 1	< 1	0.21	0.39	0.26	0.4
Pb	< 1	< 1	< 0.025	0.037	0.123	0.149
S	504	543	1110	760		
Sb						
Se	< 1	< 1	< 0.5	< 0.5		
Si	28.05	4.6	49.6	44.6		
Sn	< 1	< 1	0.05	0.32	0.07	0.25
Sr	1.31	2.33	0.431	2.42	0.446	2.09
Te						
Th						
Ti	< 1	< 1	< 0.05	< 0.05	< 0.05	< 0.05
U						
V	< 1	< 1	< 0.01	< 0.01	< 0.01	0.01
W						
Y						
Zn	116	154	213	209	197	198
Zr						
Phosphate	4				6.38	11.93

PHOSPHATE ROCK ANALYSIS

SAMPLE DATE	16-Jul-92	25-Aug-92	25-Aug-92	13-Aug-92
SAMPLE VOLUME				
ASSAYERS CODE	4083	4073	4073R	4074
SAMPLING LOCATION	SOUTH BAY	SOUTH BAY	SOUTH BAY	SOUTH BAY
	TailingP	TailingP	TailingP	TailingP
	PO4 rock	Phosphate	Phosphate	PO4
	original	precipit.	precipit.	rock
Processing code	SS	SS	SS	SS
** F I E L D **				
Temp. (C)				
pH				
Cond. (umhos/cm)				
Eh (mV)				
Acidity (mg/l)				
Alkalinity (mg/l)				
Ferric (Fe3+)				
Ferrous (Fe2+)				
** L A B **				
Temp. (C)				
pH				
Cond. (umhos/cm)				
Eh (mV)				
Acidity (mg/l)				
Alkalinity (mg/l)				
Ferric (Fe3+)				
Ferrous (Fe2+)				
ELEMENTS Ag	< 2	2	< 2	< 2
Al	5500	70700	70100	6040
As	< 10	< 10	< 10	< 10
B	364	< 2	2	269
Ba	34	11	7	34
Be	1	< 1	< 1	1
Bi	< 8	< 8	< 8	< 8
C				
Ca	311000	32200	32500	310000
Cd	5	< 1	< 1	3
Ce				
Co	< 1	< 1	2	2
Cr	58	109	108	63
Cu	99	1460	1450	92
Fe	6660	193000	172000	7390
Hg				
K	1640	678	461	1450
La				
Mg	3240	531	533	4010
Mn	74	123	123	70
Mo	< 2	< 2	< 2	< 2
Na	5750	156	170	5370
Nb				
Ni	13	4	6	11
P	89200	23300	18200	84200
Pb	< 3	49	56	< 3
S	12200	30600	22700	12700
Sb				
Se	< 10	< 10	< 10	< 10
Si	128	514	351	80
Sn	< 8	< 8	< 8	< 8
Sr	1940	182	177	1940
Te				
Th				
Ti	47	18	4	41
U				
V	20	12	13	22
W				
Y				
Zn	1320	6290	6310	1110
Zr				

WATER ANALYSES IN MILL POND CENTER

SAMPLE DATE	13-Jul-92	16-Jul-92	17-Jul-92	18-Jul-92
SAMPLE VOLUME	100	100	100	80
ASSAYERS CODE	3843	3957	3847	3956
SAMPLING LOCATION	SOUTH BAY Mill Pond MPC	SOUTH BAY Mill Pond MPC	SOUTH BAY Mill Pond MPC	SOUTH BAY Mill Pond MPC
Processing code	surface FA	bottom FA	integr. FA	PO4-botto FA
** F I E L D **				
Temp. (C)	22		23	
pH	3.78		4.38	
Cond. (umhos/cm)	1800		1550	
Eh (mV)	212		210	
Acidity (mg/l)			430	
Alkalinity (mg/l)				
Ferric (Fe3+)				
Ferrous (Fe2+)				
** L A B **				
Temp. (C)				
pH		4.4		4.9
Cond. (umhos/cm)				
Eh (mV)				
Acidity (mg/l)		675		550
Alkalinity (mg/l)				
Ferric (Fe3+)				
Ferrous (Fe2+)				
ELEMENTS Ag	< 1	0.033	< 1	0.027
Al	7.11	12	5.86	1.76
As	< 1	< 0.5	< 1	< 0.5
B	< 1	< 0.01	< 1	< 0.01
Ba	< 1	0.024	< 1	0.02
Be	< 1	< 0.005	< 1	< 0.005
Bi	< 1	< 0.05	< 1	< 0.05
C				
Ca	248	245	214	228
Cd	< 1	0.951	< 1	1.46
Ce				
Co	< 1	0.428	< 1	0.322
Cr	< 1	0.011	< 1	0.008
Cu	11.2	28	9.35	23
Fe	2.83	0.144	4.95	0.099
Hg				
K	6	6.7	6.4	8.1
La				
Mg	47.2	46.4	39.9	42.4
Mn	20.5	19.5	16.9	15.7
Mo	< 1	< 0.01	< 1	< 0.01
Na	3.67	3.56	5.01	3.73
Nb				
Ni	< 1	0.15	< 1	0.15
P	< 1	< 0.06	< 1	< 0.06
Pb	< 1	0.315	< 1	0.119
S	421	444	369	413
Sb				
Se	< 1	< 0.5	< 1	< 0.5
Si	10.47	16.5	9.35	15.9
Sn	< 1	0.32	< 1	0.28
Sr	< 1	0.396	< 1	0.391
Te				
Th				
Ti	< 1	< 0.05	< 1	< 0.05
U				
V	< 1	< 0.01	< 1	< 0.01
W				
Y				
Zn	304	237	254	247
Zr				
Phosphate			13	
TIC		6		9.5

Boomerang Lake Transects

STATION #	DEPTH	DATE	pH	COND	TEMP
TRANSECT 1-1	sur	14/07	3.33	610	18
1	1	14/07	3.34	609	17.8
1	2	14/07	3.34	610	17.7
1	3	14/07	3.34	611	17.6
1	3.5	14/07	5.22	404	17.6
2	sur	14/07	3.29	610	18.1
2	1	14/07	3.31	609	17.8
2	2	14/07	3.3	610	17.7
2	3	14/07	3.32	612	17.6
2	3.8	14/07	4.11	462	17.5
3	sur	14/07	3.28	609	18.2
3	1	14/07	3.29	610	17.7
3	2	14/07	3.3	610	17.7
3	3	14/07	3.29	611	17.6
3	3.7	14/07	4.43	440	17.5
4	sur	14/07	3.27	611	18.2
4	1	14/07	3.28	609	17.8
4	2	14/07	3.31	610	17.7
4	3	14/07	3.3	611	17.6
4	3.7	14/07	5.14	700	17.7
5	sur	14/07	3.28	610	18.2
5	1	14/07	3.29	609	17.8
5	2	14/07	3.7	610	17.7
5	3	14/07	3.31	612	17.6
5	3.7	14/07	4.68	1180	17.7
6	sur	14/07	3.28	611	18.2
6	1	14/07	3.3	610	17.8
6	2	14/07	3.31	610	17.7
6	3	14/07	3.26	621	17.6
6	3.6	14/07	3.92	1225	17.8
7	sur	14/07	3.28	613	18.5
7	1	14/07	3.3	618	18
7	2	14/07	3.29	620	17.8
7	2.2	14/07	4.67	1680	17.3
8	sur	14/07	3.28	615	18.2
8	0.95	14/07	3.25	1040	18
9	sur	14/07	3.27	613	18.2
9	1	14/07	3.27	612	17.9
9	1.3	14/07	3.27	1700	17.8
10	sur	14/07	3.26	613	18.2
10	1	14/07	3.25	612	17.9
10	2	14/07	4.89	1530	17.9

Transect 2

STATION #	DEPTH	DATE	pH	COND	TEMP
11	sur	14/07	3.26	614	18.2
11	1	14/07	3.26	613	17.9
11	2	14/07	3.26	614	17.8
11	2.1	14/07	3.19	740	17.8
12	sur	14/07	3.28	614	18.2
12	1	14/07	3.25	615	18.1
12	2	14/07	3.26	613	17.8
12	2.2	14/07	3.34	1250	17.8
13	sur	14/07	3.26	614	18.2
13	1	14/07	3.26	614	18.1
13	2	14/07	3.27	622	18.7
13	2.5	14/07	2.99	1320	17.8
14	sur	14/07	3.26	614	183
14	1	14/07	3.27	612	18
14	2	14/07	3.27	613	17.8
14	3	14/07	3.26	624	17.7
14	3.4	14/07	3.12	1020	17.8
15	sur	14/07	3.24	612	18.4
15	1	14/07	3.24	610	17.9
15	2	14/07	3.27	610	17.8
15	3	14/07	3.26	614	17.7
15	3.5	14/07	3.22	870	17.8
16	sur	14/07	3.28	612	18.4
16	1	14/07	3.29	611	17.9
16	2	14/07	3.27	610	17.8
16	3	14/07	3.27	612	17.7
16	3.7	14/07	3.68	425	17.8
17	sur	14/07	3.24	612	18.5
17	1	14/07	3.29	612	17.9
17	2	14/07	3.27	611	17.7
17	3	14/07	3.26	612	17.7
17	3.6	14/07	3.21	840	17.8
18	sur	14/07	3.25	611	18.5
18	1	14/07	3.26	613	17.9
18	2	14/07	3.27	613	17.8
18	3	14/07	3.27	612	17.7
18	3.1	14/07	3.22	630	17.7
19	sur	14/07	3.23	612	18.6
19	1	14/07	3.24	620	18.2
19	1.5	14/07	3.41	1400	18.1
20	sur	14/07	3.25	612	18.5
20	1	14/07	3.24	615	18.4
20	1.4	14/07	3.2	658	18.1